5/- / 6.35

H. K. LEWIS,
136 GOWER STREET,
LONDON, W.C.

A TEXT-BOOK OF

EXPERIMENTAL PSYCHOLOGY

A TEXT-BOOK OF EXPERIMENTAL PSYCHOLOGY

BY

CHARLES S. MYERS

LECTURER IN EXPERIMENTAL PSYCHOLOGY
IN THE UNIVERSITY OF CAMBRIDGE
PROFESSOR OF PSYCHOLOGY IN KING'S COLLEGE
UNIVERSITY OF LONDON

WITH 66 FIGURES AND DIAGRAMS

LONDON
EDWARD ARNOLD
41 & 43 MADDOX STREET, BOND STREET, W.
1909

h/

Mye

12697

PREFACE

For some time past the lack of a Text-book on Experimental Psychology has been keenly felt. The literature of the subject is now so scattered and so profuse, that a student must have at his command a small library of books and periodicals if he wishes to pursue a course of independent reading.

In endeavouring to supply this want, I do not attempt to offer a "systematic" Psychology. On the contrary, I assume that the student is already familiar with the elements of general psychology.[1] He may have had the opportunity of attending an introductory course of lectures on the subject which were accompanied by demonstrations, and in that case he will have observed how artificial is the line of cleavage between general and experimental psychology.

I assume, too, that he does not approach the detailed study of experimental psychology in ignorance of the general structure and functions of the nervous system. In the following pages I may appear at times to have laid undue stress on purely physiological and physical considera-

[1] These elements will be found clearly and concisely presented in Professor G. F. Stout's little book, *The Groundwork of Psychology* (London, 1903).

tions in their relation to the problems of experimental psychology. But the ultimate object, which has influenced me throughout, has been to describe the methods and principles of psychological experiment, and to set forth the most important results that have been obtained in this field of research.

Exigencies of space have compelled me to omit many topics of interest. I wish I could have included a chapter on the study of animal behaviour, and could have dealt more fully with experiments upon children and primitive peoples. That I have had to neglect investigations upon subconscious and abnormal states and upon the mental effects of drugs, causes me less regret; for, owing to unsatisfactory methods and insufficient knowledge, these subjects are as yet too controversial in character to come well within the scope of an Elementary Text-book.

I have purposely excluded from the text the names of all workers, save in a discussion of their views; the names of the discoverers of facts belong to the history of the science, rather than to the science itself. In a note, however, at the end of each chapter, I have inserted the titles of some important papers (bibliographical as well as experimental) and their authors' names, which, I hope, may guide the student's further reading.

The order of the chapters has been dictated by experience in teaching. I find it best to start with experimental work on sensation; this, on the whole, gives the student less difficulty, alike as regards manipulation and introspection. Owing to the fulness with which I have treated sensation, the account of experiments relating to the higher intellectual processes may possibly have suffered. I feel very strongly, however, that the best training for the

beginner in experimental psychology lies in the field of sensation. He is next introduced to certain statistical methods, which he subsequently applies to the determination of reaction times. Soon after follows the important subject of psycho-physical methods, a careful mastery of which is essential in order to perform the quantitative experiments, subsequently described.

It was only after much hesitation that I admitted a series of practical exercises into the book. Various considerations deterred me from so doing,—for example, the knowledge that teachers differ as to the details of experimental procedure which they prefer to use in their laboratory, and my experience that a too elaborately written account of practical work encourages thoughtlessness and scamping in the laboratory. On the other hand, I found that the addition of a series of exercises often enabled me to omit from the text many technical and other details which would otherwise have embarrassed the argument. I can only hope that I have given sufficient details for the exercises to prove useful to the intelligent student, who happens to be working without an instructor at his call.

I hope, too, that this book will serve to spread a more exact knowledge of the scope of the youthful science of experimental psychology. Even educated people in this country often confuse experimental psychology with spiritualistic research, or their acquaintance with the subject is limited to a hazy notion of reaction times. There are others who confuse it with the physiology of the nervous system and of the sense organs; and others again who just as wrongly style it the "new" psychology. The book may also serve to indicate the value of a training in the subject for those who intend to devote themselves subsequently

to certain other studies, more especially to education, ethnology, psychiatry, or æsthetics.

I regret that unforeseen circumstances have delayed its appearance, and I owe much to the kind forbearance meanwhile shown to me by my publisher. I have received many invaluable suggestions from Dr. A. S. Lea, Dr. H. K. Anderson, and Dr. R. N. Salaman, who have most kindly read my proofs. Dr. H. Head and Mr. Udny Yule have also helped me in Chapters II. and X. But despite the vigilance and aid of these and other friends, I dare not hope altogether to have escaped the many errors to which a book, that covers so much new ground as this, is liable.

C. S. M.

CAMBRIDGE,
February, 1909.

CONTENTS

CHAPTER I

On the Standpoint of Experimental Psychology

CHAPTER II

On Cutaneous and Visceral Sensations

CHAPTER III

On Auditory Sensations

CHAPTER IV

On Auditory Sensations (*concluded*)

CHAPTER V

On Labyrinthine and Motor Sensations

CHAPTER VI

On Visual Sensations

CHAPTER VII

On Visual Sensations (*concluded*)

CHAPTER VIII

On Gustatory and Olfactory Sensations

CHAPTER IX

On the Specific Energy of Sensations

CHAPTER X

On Statistical Methods

CHAPTER XI

On Reaction Times

CHAPTER XII

On Memory

CHAPTER XV

On the Psycho-physical Methods

CHAPTER XVI

On Weight

CHAPTER XVII

On Local Signature

CHAPTER XVIII

On Sensibility and Sensory Acuity

CHAPTER XIX

On Experiences of Identity and Difference

CHAPTER XX

On Binocular Experience

CHAPTER XXI

On Binaural Experience

CHAPTER XXII

On the Visual Perception of Size and Direction

CHAPTER XXIII

On Time and Rhythm

CHAPTER XXIV

On Attention

CHAPTER XXV

On Feeling

LABORATORY EXERCISES

EXPERIMENTAL PSYCHOLOGY

CHAPTER I

ON THE STANDPOINT OF EXPERIMENTAL PSYCHOLOGY[1]

The Relation of Experimental to General Psychology.—Experimental psychology has sometimes been styled the "new" or "scientific" psychology. It has been spoken of as if it were quite distinct from, and independent of, the older or "general" psychology, in which experiment finds no place. Now these are manifest errors. For experiment in psychology is at least as old as Aristotle. And scientific work is possible (*e.g.* in astronomy, geology, and natural history) under conditions which preclude experiment. We must regard experimental psychology as but one mode of studying psychological problems, not all of which, however, can be approached from the side of experiment. Far from being independent, experimental psychology has arisen as a refinement, of general psychology. Familiarity with the latter is essential to success in the former.

The Conditions of Experiment in Psychology.—Experiment consists in observing the play of prescribed conditions; its object is to secure accurate information. So long as the conditions are known and are controllable, an experiment

[1] The student may expect to understand the contents of this chapter more thoroughly when it is re-read at a later stage of his progress.

can be repeated by the same or by other investigators, the original observation can be confirmed or modified, and the experiment can be made to yield further information by simplification or complication of these conditions.

Experimental psychology studies the responses of individuals to prescribed conditions. Not every response, however, possesses psychological interest. Experimental psychology is directly concerned only with those responses which throw light on the analysis and the course of mental states.

The conditions in psychological experiment are the internal conditions of the individual (or subject) on the one hand, and the conditions of his environment on the other. A psychological experiment may accordingly be modified by altering either the mental attitude of the subject or the outer influences to which he is exposed.

The Response of the Subject.—The subject responds to a psychological experiment by undergoing changes in inward experience or in outward action, usually in both ways. It is clear that the former mode of response can only be studied by the subject himself; his states of consciousness, his experience throughout the experiment, can be revealed solely by his own introspection. On the other hand, his outward action, his behaviour towards the experiment, is best studied by an independent observer. For, in the first place, it is generally admitted that no man is a judge of his own actions; and, secondly, the subject's attention during a psychological experiment is, as a rule, already fully occupied in introspection. Therefore, in all but the simplest psychological investigations, the co-operation of two persons is desirable,—the subject recording his inner experiences, and the experimenter recording the subject's outward behaviour.

The Subject and the Experimenter.—If the same individual be at once subject and experimenter, he must needs prescribe for himself the experimental conditions, and is

thus in the position to observe and to appreciate the results obtained. He is, we may say, "fully informed." He knows what is about to happen, and he knows precisely what to look for. Under such conditions, auto-suggestion has full play with him: "the wish is father to the thought." He knows, too, whether he has succeeded or failed in the object of his experiment, and is encouraged or depressed accordingly.

On the other hand, if an experimenter co-operates he can arrange the experimental conditions so that the subject is more or less "uninformed," a more complete freedom from prejudice being thus attained. Then, also, the experimenter may purposely repeat the same experiment when the subject is in different stages of foreknowledge, practice, or fatigue; or he may perform it under like conditions upon different subjects.

Introspection in Experiment.—It is frequently urged that the act of introspection cannot fail to disturb the normal course of the subject's attention. An endeavour is as often made to evade this objection by the substitution of *retro*spection for introspection; which in turn prompts the further objection that memory cannot be relied upon to give a psychologically just description of a bygone experience. But the use of the experimental method reduces, even though it does not abolish, the force of each of these objections. With increasing practice, the attention can be trained to oscillate rapidly to and fro, the subject now responding to experimental conditions, now observing the contents of consciousness during his response; just as with practice he can successfully dictate a letter and read a book, to all outward appearances simultaneously.

It may reasonably be objected that the repetition of an experiment can never bring with it an exact repetition of the subject's original mental state. On the other hand, practice enables him to detect experiences which had previously escaped him, and generally to improve his memory

for bygone states of consciousness. That is to say, practice improves his power of introspection and retrospection.

Fundamentally, of course, all introspection is retrospection, and the objection to either arises, in great part, from the mistaken notion that we can ever describe *momentary* states of consciousness. It has been truly said that "neither my experience as a whole, nor the position nor relations of any part within that whole, can be given as the content of momentary consciousness. The momentary consciousness is only one link in the series which constitutes my experience."

The limits to the scope of introspection, on which stress is laid in works dealing with general psychology, are of course equally valid in the region of experimental psychology. No one can adequately perform introspection, when dominated by intense passion or by intense desire; nor can he adequately describe such experiences, when the passion or the desire has passed away. Attention to the pleasure or pain of an experience inevitably modifies that pleasure or pain. The more prominently affective or conative be a state of consciousness, the more difficult it is to study it. In such instances, especially, we may hope to advance our knowledge by observing the subject's outward action or behaviour.

The Behaviour of the Subject.—The study of the subject's behaviour always forms an important part of psychological investigation. By means of it, we are enabled to obtain numerical data which serve as an index of mental activity or sensibility; we are enabled to observe variations in the accuracy or in the mode of the response, which, aided by introspection, throw light on the nature of the conscious processes involved, or reveal differences in different individuals; we are enabled to record involuntary movements, *e.g.* movements of the limbs and changes in the circulation or respiration.

Such data clearly gain in significance when they can be

correlated with and confirmed by the subject's introspective record. Accordingly, it is a golden rule that introspection should never be omitted in a psychological experiment. There are, however, conditions under which it is impossible to avail ourselves of the aid of introspection, as in the investigation of unconscious processes, in experiments on animals and sometimes in experiments on children or savages, or on individuals in abnormal (*e.g.* hypnotic or pathological) conditions. In all circumstances the dangers of directly deducing the mental state of an individual from observation of his behaviour cannot be too strongly emphasised.

Psychology as a Science.—We are now in a position to realise that it is only the possibility of giving a physical expression to mental states which confers on general and experimental psychology the rank of a Science. This physical expression is obtained in two ways,—first by the observation of the subject's outward behaviour, and secondly by the description of the subject's inner experience. About the former we need say nothing more at present; so clearly is outward behaviour a mode of physical expression. But it may at first sight seem strange to say that when the subject describes his own mental states, he is again giving vent to physical expression. Yet such is really the case; otherwise a Science of psychology would be impossible. For from the psychological standpoint, as we have seen, no one can observe the mental states of another. Mental states are their subject's private property,—a contrast to the common property of objects of the physical world. As soon, however, as a subject takes the trouble to record his mental states, he expresses them physically. He speaks or he writes,—that is to say, he employs physical movements which are patent to and significant for his fellow men.

It is the object of experimental psychology, as of all other experimental sciences, to describe the complex in terms of the simple. Just as physics attempts to express

objective experience, so experimental psychology attempts to express subjective experience as a series of equations, reducing the complex on the one side of the equation to its elementary components on the other side.

From one aspect a certain mixture of hydrogen and oxygen is identical with an equal mass of water. From the same standpoint the binocular presentation of two stereoscopic views may be considered as identical with the single view in relief which it yields; or the simultaneous presentation of a tone with its overtones may be considered as identical with the peculiar timbre which results. But neither in chemistry nor in psychology are we satisfied with equations that have a merely existential import. Although the hydrogen and oxygen remain undestroyed during their transformation into water, we cannot overlook the fact that important alterations have taken place in their relations to one another,—that they have fused to form a chemical compound instead of being, as previously, a mechanical mixture. So, too, in our psychological examples, we cannot overlook the fact that the several tonal sensations have fused to create a totally new experience of timbre, or that the two visual perceptions have fused to create a totally new experience of relief.

Both chemistry and psychology must recognise the inexplicable nature of this fusion. The former may attempt to reduce the characteristic properties of water to terms of altered molecular composition and movement. Such so-called explanation, however, consists merely in describing the phenomena in other language, in translating them into other modes of experience. The conditions or equivalents of fusion are not its explanation; its *esse* is its *percipi*.

But this apparent similarity of psychical to chemical fusion breaks down on closer inspection. In the first place, neither the sensations nor the results of the fusion could ever be experienced, were it not that they go to form part of, and to fuse with, the subject whose experience they are.

In the second place, the very experience to which they, each or together, give rise, is determined by the past experiences and by the present condition of the subject. The experimental analysis and synthesis of the subject's experiences must therefore be supplemented by the study of the personality of the subject,—a field in which pathological and hypnotic investigations promise a rich harvest, but which lies in great part beyond the present scope of experimental psychology.

Lastly, let us remember that we are quite *unconscious* of any fusion between two (or more) simultaneous sensations or perceptions, in the examples above chosen. To be convinced of this, we have only to look into a stereoscope or to listen to the tone of a musical instrument. The complex, *i.e.* the relief or timbre, is all that we are aware of. In our ignorance we deem it simple; the different experiences of the two eyes, or the presence and interrelation of overtones, are only brought to our notice by special methods. Thus, without pursuing the subject further, we see that it is psychologically untrue to say that we first have sensation (H_2) and its companion sensation (O), which then, by the touch of a fairy wand, suddenly become transformed into a new complex (H_2O). All we can truly say is that stimuli, which separately give rise to unlike experiences, may, when acting together, give rise to a totally different complex, without evoking (or, to speak more generally, without necessarily evoking) the unlike experiences themselves.

Psychological Abstraction.—We shall begin the study of experimental psychology by considering the most elementary mental units into which we can analyse the presentations of external objects,—sensations. It might be thought that any chance stimulation of the sensory end organs of our body must inevitably yield a sensation. But, as we have just pointed out, under no circumstances are our sensory experiences isolated independent parts of our mental system.

They form with one another and with the rest of our mental system complexes which have been evolved for the express purpose of securing adjustment to external surroundings.

In our endeavour to obtain sensations in a state of requisite purity, we have often to adopt special experimental and introspective measures, stripping presentations, so far as possible, of all those characters which ordinarily make them vehicles of meaning. In the course of such processes of abstraction, we shall at times discover and study sensations, of whose nature we were previously scarcely aware, either owing to their invariable coexistence with other mental states, or owing to their relative unimportance as a means of interpreting, or of consciously adjusting ourselves to, the outer world.

It is commonly supposed that in the developing individual these simple mental states form the primary substratum from which his more complex states are subsequently developed. An exactly opposite view is nearer the truth. The clearer, simpler states should be broadly regarded as secondary to vaguer, more complex state from which they are derived through the analytic, differentiating activity of the growing mind.

Experimental in relation to Physiological Psychology.—In the study of sensations, the experimental psychologist—who investigates mental states—proceeds hand in hand with the physiologist,—the investigator of the functions of living matter. Here experimental psychology and physiological psychology are inseparable for a thorough treatment of the subject, protoplasmic activity throwing light on the ultimate analysis of sensation, and sensation throwing light on the significance of protoplasmic activity, as our knowledge of each progresses.

In other regions of psychological investigation, the connection between experimental and physiological psychology is not so close. For example, by far the most

important discoveries made by experimental psychology in regard to memory, comparison, and mental work are at present quite devoid of physiological basis. It is important early to recognise how independent the truths of experimental psychology are of the determination of the corresponding neural processes by physiological psychology.

Some psychologists, indeed, refuse to accept psycho-physical parallelism as a principle applicable to all mental processes. But provided that a proper meaning be attached to the term "psycho-physical," a thoroughgoing parallelism probably affords the best working hypothesis for experimental psychology.

"Physical" phenomena are the result of purely mechanical conditions. If those conditions are known, the result can be predicted. It is, however, only in comparatively simple, and usually in artificially established, conditions that the physiologist can accurately predict what reaction will occur with a given stimulus. The living body is characterised by unknown "vital" activities as well as by known "mechanical" activities. There are many who believe that the two differ from one another rather in degree and complexity than in kind; for the history of physiology shows how activities which had been considered as vital by one generation, have been resolved into mechanical activities by another generation of physiologists. Yet the fact remains,—and it applies especially to the nervous system of the intact animal,—the conditions are so complex and obscure that there are many physiological results which it is impossible to predict.

Similarly in psychology some experiences occur in a purely, or almost purely, mechanical manner; the conditions are so well known that a definite result may with fair confidence be predicted. But, as in the physiology of the nervous system, "mechanism" has the strictest limitations. There is thus a true "psycho-physiological" correlation, and

it is in this sense that the term "psycho-physical" parallelism must be understood.

The Aims of Experimental Psychology.—The difficulty of prediction to which attention has just been drawn, is often used to support the argument that a Science of experimental psychology is impossible. It is urged that a given individual varies at different times, and that individuals differ among themselves so greatly as to preclude the possibility of generalisation. But experimental psychology is not engaged merely with general problems, *e.g.* studying thresholds, determining the scope of attention, or fixing the limits of memory. It has also, as we shall see later, to determine how such "properties" of the mind are affected in any given individual by different conditions, and how far and for what reason they are different in different individuals. The difficulties of prediction, therefore, enhance rather than detract from the scientific interest of the subject. Similar difficulties of lower or higher order thwart our prediction of the weather or of the course of evolution: where also the conditions are too complex and too changeable for us to foretell the certainty and order of events. It is the aim of all Science, and hence the aim of experimental psychology, to analyse, so far as possible, the conditions which may be at work, and to determine the results which must follow, provided that those conditions are present.

CHAPTER II

ON CUTANEOUS AND VISCERAL SENSATIONS

THE exploration of the skin by punctate stimuli (exps. 1–7) shows that its sensibility to touch, pain, cold, and heat is not distributed uniformly over the surface. The skin contains certain " spots " which are particularly sensitive to the lightest touch, others which are sensitive to pain, others again which are sensitive to cold, and others to heat.

Touch Spots.—On hairy parts of the skin, a touch spot is to be found over the site of each hair root or follicle (exp. 4). A few touch spots are also met with between the hairs; they abound on the hairless surface of the palm and sole. A rich plexus of nerve fibres surrounds each hair follicle, the latter being the probable seat of the tactile end organ. It has been suggested that, on hairless surfaces, Meissner's corpuscles are the end organs corresponding to those of the hair follicles. At the tip of the finger, touch spots are so abundant as to be inseparable; and here the number of Meissner's corpuscles is correspondingly large. Touch spots are absent on the glans penis and, according to certain observers, on the cornea. They react to stimuli which are far too weak to excite nerve fibres directly. They react not only to pressure, but also to traction of the skin, *i.e.* to pull as well as to push; the sensation being the same for either form of stimulus. The skin is sensitive to diffuse light touch (*e.g.* to the touch of cotton wool) where punctate exploration fails to show the existence of touch spots.

Cold Spots.—They are for the most part irregularly

grouped, sometimes forming chains or clusters, but also occurring as isolated spots. It has been suggested that they correspond in distribution with the end bulbs in the skin. Individual cold spots vary considerably in sensitivity (exp. 1).

Heat Spots.—These are less numerous, and react more slowly than the cold spots (exp. 2).

The sensations derived from cold spots and heat spots, especially from the latter, are more diffuse, less definitely localisable, than those afforded by touch spots. Menthol is believed to produce its characteristic effect, by causing hyperæsthesia of the cold spots. Carbonic acid gas is said to cause a similar hyperæsthesia of heat spots.

The Two Systems of Cutaneous Sensibility.—But our sensations of pressure and temperature cannot wholly be accounted for by the reactions of the touch, heat, and cold spots of the skin. For when all the nerve fibres supplying an area of the skin have been divided, sensibility to temperature, to light touch (*e.g.* to the touch of cotton wool), and to cutaneous pain is immediately lost; but sensibility to heavier touch (*e.g.* to the touch of a pin's head), and to deep-seated pain over the same area nevertheless remains. These residual sensations must be due to the preservation and excitation of structures *underlying* the skin, situated presumably in or around tendons and muscles the nerves of which are known to contain sensory fibres.

It would seem, too, that certain other cutaneous sensations are likewise of double origin; that, in addition to the apparatus for "heat" and for "cold," demonstrated by punctate exploration of the skin, there is another non-punctate system in the skin concerned in the development of sensations of "warmth" and "coolness." More precisely, it appears that while the response to superficially painful and to hot and cold stimuli is the functional expression of one system of cutaneous sensibility, the appreciation of light touch, warmth, and coolness, and the power of precise

cutaneous localisation are the expression of another system of cutaneous sensibility. For, after injury to peripheral nerve fibres, stages occur during recovery from which one of these two systems is absent, while the other remains.

Thus, during recovery from the effects of section of a cutaneous sensory nerve, a stage has been observed in which heat, cold, and pain, corresponding to the heat, cold, and pain spots, are felt; while sensations of warmth, coolness, and light touch, and the ability to distinguish two neighbouring touches from one another, are wanting. Whereas over the normal skin the heat spots and the cold spots are set in an area sensitive to cool and warm stimuli, the result of nerve section is to produce a state in which only the heat and cold spots are present; that is to say, a state in which stimuli, having a temperature between about 26° and 37° C., produce no thermal effect. Below or above these limits, the heat or the cold spots react explosively, yielding characteristically diffuse and tingling sensations, the intensity of which is apparently independent of the degree of heat or cold, so long as the stimulus employed is at all adequate.

But this is not all. While, after nerve section, the greater part of the affected cutaneous area shows the above "protopathic" state of sensibility, small outlying cutaneous areas may at the same time be found in which sensations of heat, cold, and pain are absent, while the diffused sensibility to light touch, to warmth, and to coolness yet remains. The prick of a pin, under these conditions, is felt merely as a sensation of pointedness; the sense of pain is gone, but acmæsthesia[1] remains.

Under other abnormal conditions, this latter, "epicritic," system of sensibility may prove to be the only one present over more extensive cutaneous areas. In the normal viscera there is some evidence that it is altogether wanting,

[1] Dr. Head suggests this word as preferable to the more generally used "acuæsthesia."

the protopathic system being alone present. The protopathic appears to be more primitive than the epicritic. It is characterised by imperfect power of localisation. It is less liable to disappear and is readier to reappear than the epicritic system.

According to Head and his collaborators, to whose work these recent additions to our knowledge are due, these two systems of cutaneous sensibility compel us to assume the existence of two differently distributed systems of peripheral nerve fibres. It would lead us too far afield to discuss the cogency of this assumption. But at all events it is important to remember that, when once they have reached the spinal cord, the impulses are found arranged in quite a different manner. All thermal impulses are now grouped together, irrespectively of the system in which those impulses arise, and a similar grouping occurs in regard to the impulses of touch and pain. Further, as the impulses ascend in the cord, they cross close by the central canal to the opposite side, but the rapidity with which they cross in their ascent varies with the kind of impulse they conduct. In the case of tactual impulses, the crossing is much less rapid than in the case of painful and thermal impulses. From this brief account it is sufficiently obvious that the effects, which localised injuries to different areas of the cord produce upon sensibility to temperature, pressure, and pain, must differ profoundly from the (immediate or remote) effects of the section of peripheral sensory nerve fibres.

Pain Spots.—These are, on the whole, far more abundant than the heat, cold, or touch spots, and are always difficult to demonstrate (exps. 5, 6). They are present in the cornea, where touch spots are said to be absent. On the other hand, the sensation of pain is altogether absent over an area of the mucous membrane of the mouth corresponding to part of the cheek (exp. 8).

There are great individual differences in the sensitivity

of pain spots. Indeed, the number of pain spots that can be found within any given area depends on the strength of the stimulus employed. Herein they present a striking contrast to touch spots, which are much fewer and show little variability in threshold. Pain spots are always far less sensitive than touch spots. Nevertheless, they give rise to pain sensations, when the stimulus is too weak to excite the nerve endings directly.

Sensations of pain are more diffuse and difficult to localise, and, especially when produced by weak stimuli or in certain nervous diseases, they develop with remarkable slowness.

Pain of Non-cutaneous Origin.—As we have seen (page 12), when, owing to nerve injury or disease, the cutaneous surface has become analgesic, pain may be still produced by stimulating deeper structures. For aught we know to the contrary, specific end organs for pain may exist in the subcutaneous connective muscular, tendinous, or other tissue, similar to those which are doubtless present in the skin.

The viscera, whether healthy or inflamed, are insensitive to pain. Cutting or burning the intestines under any conditions is a painless procedure, so long as the sensitive parietal peritoneum is shielded from the stimulus. The viscera cause pain by affecting the sensitive parietal peritoneum, or by producing what has been called "referred" pain. The localisation of referred pain is determined by the distribution of the somatic sensory fibres, which belong to the same spinal segment as the visceral sensory fibres supplying the visceral area in question.

The Specific Nature of Pain Sensations.—The discovery of pain spots in the skin, and of a special grouping of fibres conducting painful impulses within the spinal cord (page 14), necessitates a reconsideration of the older view that pain may result from the excessive stimulation of any sensory nerve whatever. The existence of painless areas,

the long latency and the high threshold of pain sensations neither favour nor condemn this view. Whether it must be completely abandoned, or whether it needs only to be modified in the direction of admitting specific, as well as non-specific, pain sensations, the evidence at present is insufficient to decide. A like uncertainty attends the conjecture that pain is merely an intenser form of what is loosely termed "general" or "common sensibility" or "cœnæsthesia." Experimental psychology has left this form of sensibility practically untouched.

Temperature Adaptation.—In 1846, nearly forty years before the discovery of heat spots and cold spots, Weber suggested that the sensations of temperature are due to a rise or fall in the temperature of the skin produced by the stimulus, and that, consequently, objects which are of the same temperature as that of the skin appear to be of an indifferent temperature. This view is for many reasons unsatisfactory. The after-effects following removal of a cold stimulus (exp. 13) prove that the sensation of cold may persist while the temperature of the skin is rising. Moreover, when the temperature of the skin remains fairly constant, as in prolonged exposure to a warm fire or to cold, the sensation of warmth or cold persists, although after a time the temperature of the skin must remain practically unchanged.

We therefore conclude that our experience of temperature is dependent not upon absolute changes in the temperature of the skin, but upon the relation of those changes to the temperature to which the skin is, for the time being, adapted. Every one will agree that at a given moment the temperature of different parts of our body may feel "indifferent," *i.e.* neither warm nor cold. Yet a thermometer, applied, say, to the tongue and to the ear, will register about 37° and 29° C. respectively. It is also a familiar fact that the temperature of a room which feels warm or indifferent in winter, will appear quite cool on a

hot summer's day. These are extreme cases, but they exemplify the general rule that the indifferent temperature varies according to the temperature to which the body or part of the body has become adapted.

Recognising these important facts, Hering suggested that sensations of temperature are the result of raising or lowering the body's indifferent temperature, which may itself fluctuate within certain fairly wide limits. He termed this variable indifferent temperature the "intrinsic" or "adequate" temperature, or the "physiological zero." It is the temperature to which the body, or particular area of the body, is for the time being adapted. Further, he suggested that sensations of heat and cold may be attributed to two opposite metabolic processes, of "dissimilation" and "assimilation," occurring in a common hypothetical temperature apparatus. During the state of adaptation, these two processes are both excited and are in equilibrium, the process of assimilation (or building up) being equal to the process of dissimilation (or breaking down). Hering supposed that if the conditions of adaptation be now disturbed, say by a rise of temperature, the dissimilation process at first preponderates, and hence a sensation of heat results. Dissimilation, however, proceeds faster than regeneration of the dissimilated substances can occur within the temperature apparatus. Hence the amount of dissimilation becomes less and less, although the exciting temperature change persists. Ultimately, the dissimilation process is so far reduced, that it is balanced by the process of assimilation which has meanwhile always been operative in some slight degree.

Thus a new state of equilibrium is attained,—a state of equilibrium at a *low* level of metabolism, since nearly all the store of material available for dissimilation has been spent. Hering supposed that (within certain limits) equilibrium may be produced at high as well as at low levels of metabolism, and he suggested that such

changes in the position of equilibrium correspond to changes in the physiological zero, the temperature of adaptation.

Since Hering's theory was propounded, separate "spots" have been discovered for heat and for cold, and it has become difficult to reconcile the peripheral isolation of the end organs with the requirements of the theory. But the quite recent discovery of an additional "epicritic" mechanism, concerned in developing sensations of warmth and coolness (page 12), gives a possible anatomical basis for the occurrence of a balance between assimilation and dissimilation within a single peripheral sensory apparatus. For we have evidence that while heat and cold spots are incapable of adaptation, adaptation is an important determinant of the temperature sensations derived from the epicritic system.

Whether we accept or reject Hering's theory, we cannot neglect the facts which it attempts to embrace. We must always bear in mind that the effect of a thermal stimulus upon sensation depends not merely on the intensity, duration, and extent of the stimulus (exp. 10), but also on the temperature to which the skin is at the moment adapted (exp. 11).

Touch Adaptation.—It is interesting to note that similar conditions of adaptation prevail in our experiences of touch. The tactual sense becomes adapted to the pressure of our clothes, to novel pressures, *e.g.* when eyeglasses are first worn, and to the removal of normal pressures, as when a tooth is extracted.

Other Cutaneous Experiences.—Our analysis of such experiences as roughness, smoothness, dryness, wetness is as yet too imperfect for us to decide as to their nature. In each we are probably dealing with the effects of summation and fusion of various elementary sensory processes.

Tickling appears to depend on cutaneous sensations arising not only from touch, but also from the reflex contractions of the unstriated muscle fibres of the skin. The

peculiar feeling tone, the irradiating character, and the tendency to produce far-reaching reflex actions are remarkable, both in tickling and in itching.

BIBLIOGRAPHY.

E. H. Weber, "Der Tastsinn und das Gemeingefühl," in *Wagner's Handwörterbuch d. Physiol.*, 1846, iii. (2), 481 (reprinted separately by Engelmann, Leipzig). E. Hering, "Der Temperatursinn," in *Hermann's Handbuch d. Physiol.*, 1880, iii. (2), 415. H. Donaldson, "On the Temperature Sense," *Mind*, 1885, x. 399. M. von Frey, "Beitr. zur Sinnesphysiol. d. Haut," *Ber. d. sächs. Gesell. d. Wiss.* (Math.-phys. Classe), 1894, 1895, 1897. A. Goldscheider, *Gesammelte Abhandlungen*, Leipzig, 1898, i. C. S. Sherrington, "Cutaneous Sensations," in *Schäfer's Text-book of Physiol.*, Edinburgh and London, 1900, ii. 920. T. Thunberg, "Physiologie d. Druck, Temperatur und Schmerzempfindungen," in *Nagel's Handbuch d. Physiol. d. Menschen*, Braunschweig, 1905, iii. 647. H. Head, W. H. R. Rivers, and J. Sherren, "The Afferent Nervous System from a New Aspect," *Brain*, 1905, xxviii. 99. S. Alrutz, "Die Kitzel- u. Juckempfindungen, *Skand. Arch. f. Physiol.*, 1908, xx. 371.

CHAPTER III

ON AUDITORY SENSATIONS [1]

The Physical Basis of Pitch and Loudness.—In general, our auditory sensations are due to the occurrence of sound waves in the external air. These waves vary in length, in amplitude, and in form. Other things being equal, the shorter the wave length (*i.e.* the greater the vibration frequency) the higher in pitch will be the auditory sensation; and the greater the amplitude (*i.e.* the more distant the crest or trough of a wave from the position of equilibrium) the louder or more intense will be the auditory sensation. But these relations are only broadly true. For, as we shall see, the pitch and the loudness of our sensations do not always correspond to the wave length and the amplitude of the objective stimuli.

[*The Conduction of Sounds to the Inner Ear.*—Sounds which are of moderate pitch and loudness are led to the inner ear by the membranes and ossicles of the middle ear. It has been experimentally shown that the ossicles vibrate with a frequency dependent on the vibration frequency of the sound stimulus, and that they must consequently be regarded, not as a fixed conducting rod, but as a jointed, freely vibrating chain.

If, however, the sounds be loud enough or be of sufficiently high pitch, they are audible to persons who through injury or disease have altogether lost this mem-

[1] The student is recommended to omit at his first reading those portions which are enclosed in square brackets [ ].

branous and bony apparatus of the middle ear. It has been demonstrated that high or very loud sounds are directly communicable from the air to the inner ear by way of the bony walls of the skull. Under normal as well as under abnormal conditions of health, there can be little doubt about the occurrence of such direct bone conduction in the case of high or very loud sounds.]

[*The Conduction of Sounds from Ear to Ear.*—Direct bone conduction also occurs when a sounding instrument, *e.g.* a tuning-fork, is brought in contact with the head or teeth (exp. 15). It is likewise a factor of considerable psychological importance when a sound is led to one ear only (exp. 16); for unless the sound be low in pitch and intensity, it travels to the opposite ear, partly perhaps by way of the two Eustachian tubes across the pharynx, but chiefly over the bony vault and across the base of the skull. For this reason we are practically unable to excite the auditory end organs of one side of the body without simultaneously exciting (of course, in less degree) the corresponding organs of the opposite side,—an experimental difficulty which it is most important to bear in mind.]

The Physical Basis of Timbre.—We have seen that the pitch and the loudness of sensations of sound are closely connected with wave length and amplitude, but we have yet to examine a feature in which sound waves further differ from one another, namely, variety of form. The vibrations of a sound wave, if wholly devoid of regularity, are termed "non-periodic." They are termed "periodic" when during equal periods of time, however long, the same movements are repeated, however complex. Further, periodic vibrations are classified as "pendular" and "non-pendular."

Pendular vibrations produce a particular form of sound wave, the "sine wave," which is important because theoretically it gives rise to the purest sensation of a single

tone.[1] All other periodic vibrations are non-pendular. It is commonly stated that non-pendular periodic vibrations produce composite or complex tone sensations, and that non-periodic vibrations produce sensations of noise. We shall presently see that these statements are only broadly true; but before we can advantageously study the psychological effects of pendular, non-pendular, and non-periodic vibrations, it is important to grasp the significance of a mathematical theorem and of a physical principle of acoustics, which are closely connected with the physiology and psychology of hearing. These are "Fourier's theorem" and the "principle of resonance."

Fourier's Theorem.—This theorem states that a non-pendular periodic wave may always be resolved into a series of pendular waves. The longest of these pendular waves has the same frequency as the non-pendular wave, and the other pendular waves of the series have 2, 3, 4 . . . times that frequency. Any one or more members of such a series may be missing. The number of members is commonly infinite, but the amplitude of the higher members is usually so small that the first few component waves suffice to give an approximation to the original non-pendular wave.

Resonance.—The principle of resonance or of sympathetic vibration concerns objects that have a natural rate of vibration which they execute more readily than any other rate. A confined chamber of air, or a stretched string, forms an admirable resonator. Let us, for purposes of illustration, choose the latter object, and let us suppose that its tension is such that, when struck or bowed, it executes two hundred vibrations per second, emitting a tone of this vibration frequency. Let us suppose that the string is at

[1] This form of sound wave is called the "sine wave" because at any instant the displacement of any particle from its position of equilibrium is proportional to the sine of an angle, which in turn is proportional to the distance of that particle from the rear of the wave. Within the length of a wave this angle increases from o to 2π.

rest, and that sound waves, having precisely this vibration frequency, now travel to it through the air, generated from some extraneous source. The resting string will at once vibrate sympathetically. It is thrown into its natural rate of vibration, resonating to the vibrations of the air.

The principle of resonance can be best understood by comparing the resonant object to a freely swinging pendulum. Imagine a pendulum of such a length that it executes a complete oscillation (to and fro) in one second. Let it start from at rest, and receive a series of infinitesimally minute taps which are regularly given at intervals of a second. Then every tap, if given at the very start of a pendular excursion, will serve to increase, ever so slightly, the extent of the following excursion; the ultimate result being that the pendulum will swing with a very wide excursion. It is just the same in the case of our example of the resonating string, the natural vibration period of which is two hundred times more rapid than that of the pendulum. The regular condensations (and rarefactions) of the advancing sound waves correspond to the taps received by the pendulum. A succession of such minute thrusts (and pulls), administered with appropriate frequency, finally produces relatively powerful vibrations in the resonating string.

If the rate of taps given to the pendulum do not accurately accord with its natural rate of swing, their effect, of course, is not so favourable. So, too, the string resonates more and more feebly, the less exact be the correspondence between the pitch of the reinforcing tone and the natural vibration rate of the string; until ultimately, when the discrepancy is too great, there will be no resonance effect at all. When a string can be forced to resonate at all by such non-corresponding vibrations, it vibrates in the period of the latter, but it immediately returns to its natural period of vibration when those vibrations cease to act on it.

We have already observed (page 21) that a pure tone sensation is theoretically produced by the pendular vibrations

of a sine wave. Let us now suppose that several sine waves of different wave lengths are brought simultaneously before a single resonator. In other words, let us suppose that several pure tones of different pitch are simultaneously sounded before a single resonator. The resonator will immediately pick out that tone to which it is attuned, resonating powerfully thereto. A moment's consideration will show that the sound vibrations acting on the resonator, although periodic, are no longer pendular; they are the resultant of the simultaneous movements imparted to the air by pendular waves of different length. But the resonator has the power of analysing these complex periodic non-pendular vibrations; it responds to that particular pendular component to which it is attuned. Only a sufficiently large series of appropriate resonators is needed in order completely to analyse a number of simultaneously sounding tones, however great (exps. 17, 18).

On the mathematical side, this physical resolution of mixed tones finds its counterpart in Fourier's theorem, to which we need not refer again here. On the psychological side, it is a matter of common knowledge that the practised musician can readily analyse a group of simultaneously sounding tones into its components, if they be not too numerous or of too nearly identical pitch. It was this similarity between physical and psychical behaviour that led Helmholtz to suppose that the cochlea contains a series of resonating fibres, differently attuned, each selecting its appropriate pendular constituent of the non-pendular periodic vibrations reaching the inner ear. We shall later (page 51) discuss this theory of hearing in detail.

Most resonators, besides being capable of vibrating as a whole, may vibrate in halves, in thirds, in quarters, etc., each section or internode executing twice, three, four, etc., times as many vibrations per second as the entire resonator. Thus, a resonating string, or a hollow tube, may be thrown into sympathetic vibration by sound waves, the period of

which is any simple multiple of the vibration frequency to which the entire string or chamber is attuned.

[*The Middle Ear.*—We are now in a position to study the function of the parts within the middle ear. The tympanic membrane is drawn inwards at its central region by the handle of the malleus, to which it is attached by its layer of radially disposed fibres. The malleus is in turn pulled inwards by the action of the tensor tympani muscle, and the radial fibres of the tympanic membrane are bent convexly outwards, chiefly owing to the constricting action of the layer of circular fibres.

Experiments have shown that such a curved membrane has the advantage of possessing only feeble powers of resonance. Were the tympanic membrane flatter, denser, and freer, it would resonate more powerfully to one particular tone than to others,—a feature obviously harmful to good hearing. Its peculiar form and connections allow it to respond fairly equally to the wide range of tones to which the ear is sensible (exp. 19).

The tensor tympani muscle contracts when the sounds are very high or loud. It has been supposed, on insufficient grounds, that by increasing the curvature and tension of the tympanic membrane, this muscle protects the membrane from excessive vibration, and thus from risk of damage. It has also been supposed that the tensor tympani muscle contracts with different force according to the pitch of the tone stimulus, tuning the membrane so that it responds with maximal sensitiveness to tones of different pitch. But the experiments that have been advanced in favour of this accommodatory function of the muscle are not convincing. They were performed on dead animals, the tension of the membrane being varied by applying different degrees of artificial traction to the tendon of the muscle.

The position of the stapes is controlled by the stapedius muscle, which contracts during attentive listening. Its action is to pull the ossicles towards the tympanic mem-

brane, lessening the curvature of the latter. Consequently the pressure within the inner and middle ear falls, the tympanic membrane vibrates more freely, and the keenness of hearing is increased. On the other hand, the pressure within the middle ear is raised during yawning (owing to the accompanying contraction of the tensor tympani), or when air is forced through the Eustachian tube into the tympanic cavity: in either case a marked damping of loud and deep tones results.]

[*The Relations of Noise to Tone.*—In order that pendular vibrations of the air may produce a sensation of tone, their number that reaches the ear must not fall below a certain limit. Below that limit the auditory sensation produced by the vibrations is one not of tone, but of noise, in which it is impossible to recognise a precise pitch. According to the methods employed, the various attempts which have been made to determine the minimal number of vibrations necessary for a tone sensation have differed considerably in result. A serious obstacle to the success of such experiments lies in the generation of secondary sound waves arising from reflexion and other causes. The investigator can never be satisfied that the exact number of vibrations which he has so carefully produced will not be augmented by a train of others before the inner ear is reached. Several recent observers, however, agree that throughout a considerable range of tones only two pendular vibrations need be generated in order to produce a tone sensation. But more than two vibrations are required in order that the pitch may be with certainty recognised.

Hence it is incorrect to say that, whereas noise results from non-periodic vibrations, sine waves, *i.e.* periodic vibrations, always produce sensations of tone. We have just seen that if the sine waves be too few in number, a sensation of noise, not of tone, results. Further, when various sine waves are simultaneously produced, which are nearly, but not quite, of identical wave length, a sensation of noise

is produced. This effect is easily obtainable by pressing two long boards on the keys of the pianoforte, so as to strike a series of neighbouring black and white notes simultaneously. But the effect is still noisier, if the tones sounded differ less in pitch than those of this instrument (exp. 20).

Noises have been divided into two classes—momentary and continuous. A momentary noise, *e.g.* the noise of an explosion or of an electric spark, is sometimes stated to be the effect of a single sound wave. Continuous noises, *e.g.* the rustling of leaves or the roar of waves, are sometimes described as the sum of small momentary noises. But the objections, which we have just urged, against the action of single sound waves are also valid here.

Having reviewed the physical, we may pass on to the psychological relations between tone and noise. A discussion of their physiological relations will be deferred until we come to consider the general theories of hearing (page 55). It is often said that a noise is as different from a tone sensation as white is different from a colour sensation. Certainly, in their purest form, noise and tone are fundamentally different experiences. The one is unpleasant, rough, irregular, and difficult to analyse; the other is pleasant, smooth, regular, and relatively simple.

It is clear that every gradation may occur between a sensation of noise and one of tone, *e.g.* between the noise resulting from rubbing a table and the tone resulting from rubbing a finger-glass. One reason for the possibility of this gradation lies in the fact that there are few noise stimuli that do not contain tone stimuli also. Tones of definite pitch may be detected in the roar of a waterfall or amid the hum of traffic in the heart of a busy city. Resonators will help in the identification of such tonal components of noises. But even a quite toneless noise is not devoid of pitch, although the latter can be estimated only vaguely. For, after a little practice, we can definitely

say that one noise is higher or lower than another, although we are unable to determine its precise pitch (exp. 20).]

Timbre.—If nearly all noises contain tones, it is likewise true that the production of tones involves noise. It is impossible to name an instrument which can emit a noiseless tone. In the horn noise arises from blowing, in the piano from striking, in the harp from plucking, and in the violin from bowing the instrument.

Now it is obvious that the sounds of these several instruments differ from one another, apart from their specific accompanying noises. A tone of a given pitch on the bassoon is not to be mistaken for a tone of the same pitch on the piano or on the violoncello. The difference does not lie in noise, pitch, or loudness, but in a quality which we call "timbre" (exp. 21).

Tone Nomenclature.—Before we examine the basis of this experience of timbre, it is convenient to describe the nomenclature usually applied to the range of tones. The middle c on the pianoforte is written c'; its vibration frequency is 256 per second.[1] The next c, with a vibration frequency of 512, is written c'', the c above which (1024 vibrations) is written c''', and so on. The c below c' is c°, the c below this is C_0, below which are C_1 and C_2. The "major scale" from c' to c'' is therefore written—

c'	d'	e'	f'	g'	a'	b'	c''
256	288	320	$341{\cdot}\dot{3}$	384	$426{\cdot}\dot{6}$	480	512

The octave in which this scale is written is called the once-accented octave. Above it come the twice, three times, four times, etc., accented octaves. Below it the octaves are successively named the small, the great, the contra- and the subcontra-octaves.

[The figures below the above notes give the vibration frequency. The relation of c' to c'' ($256 : 512 = 1 : 2$) is that

[1] This is the pitch of c' adopted for scientific purposes. As a matter of fact, the middle c of the English pianoforte has a vibration frequency of about 270.

of a tone to its "octave"; $c' : g'$ (2 : 3) forms the interval of a "fifth"; $c' : f'$ (3 : 4) forms a "fourth"; $c' : e'$ (4 : 5) forms a "major third"; $c' : a'$ (3 : 5) a "major sixth." The above together with the "prime" ($c' : c' = 1 : 1$), the "minor third" ($c' : e'^{\flat} = 5 : 6$) and the "minor sixth" ($c' : a'^{\flat} = 5 : 8$), are the "consonant" or pleasing intervals within the octave. The "dissonant" or disagreeable intervals include the "major second," $c' : d'$ (8 : 9), the "minor second," $c' : d'^{\flat}$ (15 : 16), the "major seventh," $c' : b'$ (8 : 15), and the "minor seventh" $c' : b'^{\flat}$ (5 : 9). Mention may also be made of an "augmented fourth" $c' : f'$ (32 : 45), called the "tritone," which is nearly identical with the ratio 5 : 7. The latter interval and the interval 4 : 7, which do not occur in our musical scales, are intermediate between the consonances and dissonances. Intervals wider than the octave, *e.g.* the "twelfth" (1 : 3) $c' : g''$, or the "major ninth" (4 : 9) $c' : d''$, have the same relations as corresponding intervals ($c' : g'$, $c' : d'$) within the octave.

The first note of the scale is called the "tonic." In the major scale, described above, all the intervals reckoned from the tonic are major. Minor intervals appear only in the minor scales. Let us for the moment restrict our attention to the major scale, and let us proceed to construct another major scale, making *d* the tonic in place of *c*, and calculating the vibration numbers of the tones that lie a major second, a major third, a fourth, a fifth, a major sixth, and a major seventh above the tonic. Then we shall find that only two of these six tones are already represented in the scale of *c*. When further we similarly calculate the tones of the major scales of *c*, *f*, *g*, *a*, and *b*, we find that altogether eleven additional tones are required within the octave. So, too, in order to play the minor intervals it will be found that eight additional tones are required.

Now, in order to reduce the enormous number of notes which would thus be needful for us to play major and minor scales from all possible tonics, a system of equal

temperament has been employed in tuning the pianoforte and similar instruments. The tones between each octave are divided into twelve equidistant semitones, the result of which is that the only exactly intoned interval is the octave. All the other intervals in such tempered instruments are more or less, but so slightly, out of tune, that we can start a scale on any tonic we please. In other words, we can play a melody in any key we like.]

The Relation of Overtones to Timbre.—Hitherto we have spoken of pendular vibrations of sound waves and of the corresponding pure tone sensations as if they had real existence. We have now to qualify this notion very materially. There is no known source of sound that produces a pure tone sensation. If an instrument be sounded so as to produce a tone, say of 500 vibrations per second, we cannot avoid the simultaneous production of other tones which, in many cases, are simple multiples of that tone. We speak of the tone 500 as the "primary" or "fundamental" tone. The tones which accompany it, having vibration frequencies of 1000, 1500, 2000, etc., are called "harmonics" or harmonic "overtones." The number and loudness of these various overtones vary in different instruments, and determine the "colour" or timbre of the tones produced. A little care will enable even the unmusical observer to detect various overtones in a note of the piano or violin. By means of resonators the overtones may be accurately indentified (exp. 22). It is found that the dull sounds of the flute are poor in overtones, that the piercing sounds of brass instruments are especially rich in the higher overtones, and that the nasal quality of the clarionet is due to the feebleness of the odd series of overtones (first, third, etc.), and to the loudness of the higher members of the even series. Similar analyses have been applied to the vowel sounds of our voice. One vowel differs from another of the same pitch owing to the number and loudness of the overtones generated (exp. 23). Indeed, by combining a

number of appropriate tones of suitable loudness, we may synthetically produce different vowels with very fair success.

The tuning-fork is chosen for auditory experiments because of the great purity of its tone. But even here the first overtone may be sometimes detected, while other overtones which are not simple multiples but "inharmonic," are often present as in many other instruments.

[A tone which is poor in overtones not only has a duller timbre, but actually appears to be lower in pitch than a tone rich in overtones. This fact has been used to explain the rise of pitch which is observable as the tone of a tuning-fork dies away, or as a fork is slowly withdrawn from a position close to the ear. Distance is believed to affect the apparent strength of a primary tone more than that of its overtones.

But if the timbre of the tones produced by various orchestral instruments depends on the nature and loudness of the overtones, we may well wonder how we can determine that a given tone or a phrase in a piece of orchestral music is being played by a particular instrument. The various tones and overtones reach the ear in complete disorder. How then, we may ask, can the overtones be sorted out and allotted to the fundamental tone to which they belong so that that tone regains its original colour? In point of fact, even the most experienced musican is, under certain conditions, liable to erroneous judgment. But our ability, remarkable as it is, is chiefly due to past experience, to differences in the position of instruments in the orchestra, to movements of our head whereby we are able to vary concurrently the loudness of the tones and of the overtones of any one instrument, and to the different course of the phrases of tones played by different instruments of the orchestra. The last-named factor is doubtless of extreme importance. For every variation in time, loudness, or pitch which the fundamental tones of an instrument undergo

must be similarly shared by their overtones. This provides a means of allotting the overtones to their proper fundamental tones.]

[*The Threshold of Intensity.*—In order that a tone or a noise may be heard, the intensity of the stimulus must not fall below a limiting or "liminal" value. The value of this "limen" or "threshold" varies according to the nature of the sound, the simultaneous presence of other sounds, the acuity of the subject's hearing, and the method of estimating the threshold. We shall refer again to these conditions when we come to treat of sensory acuity and attention (chapters xviii. and xxiv.).

If, on the other hand, the loudness of the purest obtainable tone be too great,—that is, if the degree of displacement of the vibrating particles from equilibrium be too great relatively to the magnitude of the force that displaces them,—overtones are produced and the tone no longer preserves its original purity.

There is a general tendency for the pitch of loud sounds to appear too high, and conversely for the pitch of faint sounds to appear too low. This illusion is partly due to the change of timbre (page 28) arising from differences in the ratio of the fundamental tone to the overtones. It is, however, doubtless also connected with the greater psychical intensity of high tones as compared with that of low tones (page 35).

Before a sound stimulus produces a sensation, it has to overcome what we may describe as the inertia of the auditory apparatus. If we place the ends of a rubber tube one in either ear, and if we gently rest a very weakly vibrating tuning-fork, preferably of low pitch, on the midpoint of the tube, the tone will at first be inaudible, will later be heard, and will then gradually increase in loudness, the sensation reaching its maximum after one or two seconds. The time thus spent in evoking an auditory sensation is in part due to changes produced in the inner

ear, in the auditory nerves, and in the cerebral centres with which the latter directly or indirectly communicate. But it is chiefly due to the inertia of the apparatus of the middle ear, which has to be overcome in order that the resting ossicles may execute their proper vibrations. Persons whose ossicles vibrate with difficulty owing to disease (whose auditory acuity is therefore subnormal) may not be able to hear a loudly sounding tuning-fork until it has been held for several seconds before the ear. Such subjects can often hear distinctly better when they travel, or when they are in a room where noisy conversation is being carried on. Apparently the rattle of the carriage or the general buzz of voices stirs their ossicles into movement, so that the latter become more sensitive to auditory stimuli.]

[*Auditory After-sensations.*—Not only is there a latent period between the application of the stimulus and the development of the auditory sensation, there is also a period during which the sensation persists after the withdrawal of the stimulus. This, again, is in part due to the persistence of peripheral and central nervous processes; but it also arises from the after-vibrations of the ossicles of the middle ear. Unfortunately the attempts hitherto made to determine the duration of these "after-sensations" are of too unsatisfactory a character to be given in full detail here. The usual procedure in such experiments has been to interrupt a given tone stimulus, or to alternate two different tone stimuli, so rapidly that a continuous (or an interrupted) experience is just produced. The varying results are partly attributable to different experimental methods. But the chief and most obvious objection to such experiments lies in the fact that the determination of any given after-sensation is complicated by the time occupied in the development of the following sensation. The course of each auditory sensation must be regarded as a curve, slowly reaching its maximum after the stimulus is first presented, and declining

gradually after the stimulus has been withdrawn. When two such curves rapidly follow so as partially to overlap one another, it is clearly hopeless to endeavour to determine the duration of one component of one curve, if the duration of other components of the other be quite unknown.

These after-sensations of hearing must be distinguished from certain continuous or intermittent "revived sensations" which are far rarer and are sometimes referable to pathological disorder. They are said to occur more frequently among subjects whose hearing is subacute. Their onset usually follows some fifteen or more seconds after the stimulus has been withdrawn, but this is not always the case. After prolonged experiments during the day with the highest audible tones, they may recur at night and their vividness may be so intense that they may be confused with sensations of objective origin. In most instances of revived sensations it is highly improbable that they are due to after-vibrations of the ossicles of the middle ear. In some cases the absence of beats (page 37) or difference tones (page 42), when revived sensations of different pitch are simultaneously present, points to a neural or central origin. They are probably akin to visual hallucinations, and are perhaps the result of abnormal nervous excitability (exp. 24).

Even when all the effects of a sound stimulus have passed away, the end organs of the ear do not enjoy complete rest. They are perpetually being played upon by feeble stimuli of internal origin, due, for example, to the circulation of the blood or to muscular contractions within the ear; although it is to this condition that we give the name of silence. In "singing in the ear" such intra-aural disturbances reach a distressing intensity.]

Tone Character.—Tone sensations of different pitch vary in a quality which we may call "tone character" (exp. 25). A very high tone sensation appears thin, pointed, and piercing, a very low tone sensation appears coarse, voluminous, and massive. These special characters of tone

sensations are in part dependent on the loudness, number, and pitch of the accompanying overtones and on the beats to which neighbouring overtones give rise. They are also in part the outcome of association with the instruments which produce the tones; the double bass, for example, suggesting the sombre immensity of low tones, the trumpet suggesting the brightness and fineness of high tones. Yet this is not a complete explanation of tone character. Sensations of tone (and to a less extent, sensations of noise) appear to contain a certain spatial quality, a character of voluminousness, which is dependent on pitch. This tone character is perhaps analogous to the extensity of visual and tactile sensations. Conjecture may relate it either to the length of the sound wave or to the number of simultaneously excited hair cells within the cochlea.

Variations in tone character make it extremely difficult to compare the intensities of tone sensations of very different pitch. We may decide without trouble that c''' and c^{iv} are equally or differently loud, but we may be utterly baffled in comparing the loudness of e''' and C_1.

Of two moderately pitched tone stimuli having equal physical intensity, that which is the higher in pitch will give the more intense sensation. This intenser psychological effect of higher tones is probably closely related to the special tone character which they possess.

[*The Intensity of Simultaneous Tones.*—Although we may with fair accuracy compare the intensity of two successive tone sensations which are nearly alike in pitch, we should be wrong in supposing that when a number of tones are simultaneously sounded, the intensity of the whole experience depends on the sum of the intensities of the different tone sensations which are present. Provided that the tone sensations are not identical, the total intensity effect is independent of their number. So far, indeed, as the component sensations are concerned, they may appear individually to lose in loudness when excited simultaneously.

This is particularly the case when high and low tones are sounded simultaneously. A high tone appears much louder alone than when sounding with a low tone. Low tones tend to suppress or to obscure accompanying high tones (exp. 26). It may be that this feature is again the outcome of the massive tone character of lower tones; there may be some obliterating interaction in the end organ, in the peripheral nerves, or in the auditory centre. At present we are unable to decide.]

The Range in Pitch of Audible Tones.—If we gradually raise the pitch of a tone, *e.g.* by shortening the length of a pipe, the tone becomes more piercing, it grows finer and feebler, and the continuing change in pitch becomes less perceptible, until finally the tone ceases altogether to be heard. The upper limit of hearing has been passed. If we gradually lower the pitch of a tone, it becomes more voluminous, intermittent, and noisy, until it passes into a series of pulses which have the character rather of thrusts or blows on the tympanic membrane, than of sounds.

The range of hearing varies in different animals. In man it comprises about eleven octaves, but the limits are ill-defined, depending on the age and practice of the subject and on the loudness of the tone. Whistles (exp. 27), strings, organ pipes, tuning-forks, metal rods, and toothed wheels have been used for determining the range of hearing. Difference tones (page 42) and interruption tones (page 46) have also been employed. The difficulty in determining the lower limit consists in the presence of overtones; the first overtone being readily mistaken for its fundamental, and so leading to an erroneous result. In estimating the upper limit of hearing, it is important to use a source of tone production which will emit a tone of constant pitch. The notes of the minute whistle (Galton's whistle), which is usually employed, vary considerably in pitch according to the pressure of the wind blowing it. The upper limit is also influenced very sensibly by the intensity of the tone, a

feeble tone being inaudible while a louder one of the same pitch may yet be heard.

The lower limit of hearing is a tone of from fifteen to twenty vibrations per second. The upper limit is a tone of about 22,000 vibrations per second. From youth onwards the range narrows at both ends, becoming reduced in old age by about an octave. By no means the whole of this available range of about eleven octaves is employed in music. The notes of a grand pianoforte extend over a distance of less than eight octaves, from A_2 ($26\cdot\dot{6}$ vibrations) to c^{v} (4096 vibrations); the organ has a range of nine octaves from C_2 to c^{vi}.

[*The Smallest Perceptible Difference of Pitch.*—Some of the conditions which affect our ability to discriminate between small differences will be alluded to hereafter (Chap. XIX.). The smallest interval that we can detect between two successive tones is known as the differential threshold, or as the threshold of discrimination, for successive tones (exp. 120). Over the middle part of the tone range it is fairly constant. Practised observers are just able to detect differences in the case of the following pairs of tones:—64, 64·15; 128, 128·16; 256, 256·23; 512, 512·25; 1024, 1024·22; 2048, 2048·36. Judgment of difference, however, is easier than one of direction of difference. The pairs of tones just named are too nearly alike for the observer to decide which is the higher or the lower, even though he may be able to detect a difference between them. Towards the upper and lower limits of the range of audible pitch, discrimination becomes less delicate. Indeed, near these limits, the threshold of discrimination becomes astonishingly high.]

Beats and Intertones.—If two tones of nearly identical pitch are simultaneously sounded, "beats" occur, the frequency of which depends on the vibration difference of the tones (exp. 29). They are due to the mutual interference of the two tones. Such interference may be proved by mathematical and physical methods to take place in the

air external to us. If two series of pendular waves be drawn on paper and compounded together, the one containing x, the other $x+y$ vibrations per second, it will be found that in every second there are y periods of rest, *i.e.* y interruptions or beats, due to mutual interference of the two series. We shall later (page 53) have occasion to discuss whether our experience of beats is to be ascribed directly to this external interference or to the occurrence of interference within the ear. For the present this need not detain us.

Let us sound together two tones of the same pitch, c' $(=256)$. So long as they are absolutely in unison we have a perfectly uniform tone sensation. Now let one of these "primes" be slightly raised in pitch, and we shall still hear a single tone, although we have no longer a continuous tone sensation. The tone regularly swells and falls in loudness; in other words, it "beats." The beats are well marked and may be counted until the pitch of the mistuned prime begins to exceed 264 vibrations. If we raise its pitch still further, we note that as the interruptions become more rapid they also become more discontinuous, more "beat-like." The rise and fall of intensity now occur with great suddenness. The change is just as if a sea of waves were becoming increasingly pointed, and less rounded. About the same time unpleasant tactile sensations—due to tremor of the tympanic membrane—begin to be felt, and the beats begin to be accompanied by noise. When a pitch of about 272 vibrations is reached, the beats are most thrust-like and evident; here the maximum difference between a rise and fall of loudness is attained. Beyond this point the noise and the unpleasant tympanic tremor become greater, and the individual beats seem to grow smaller and flatter. The most disagreeable effect occurs when the variable tone reaches about 284 vibrations. From now onwards a complete separation of the beats becomes more and more difficult. They begin to rattle and to "burr," and ulti-

mately they give a feeling merely of roughness. Even at 300, interruptions are with care still recognisable. At 308 all trace of them disappears (exp. 30).

Four stages may thus be recognised, as the frequency of the beats is increased. In the first stage they have a surging, in the second a thrusting, and in the third a rattling character; finally they fuse and pass into a stage where only roughness remains, beyond which they completely disappear. But these four stages, although recognisable in the middle region of the tone range, are modified in the upper and lower regions. For example, the rattle met with in the mid-region becomes a chirp in the upper region; and the beats of very low tones disappear without reaching the stage of roughness. Beats of a given frequency which can still be counted in the middle tone region are too confused to be counted in the lower. In the example given above, the beats disappear when the variable tone is one of about 308 vibrations per second, *i.e.* when it is near $e'^{\flat}$, making an interval of nearly a minor third with c'. On the other hand, the tone C_0 (64 vibrations) just ceases to beat with its fifth G_0—a difference of 32 vibrations. Indeed, the limiting interval for the beats of mistuned primes varies according to the tone region. For example, c^{v} (4096 vibrations) ceases to give even a feeling of roughness with tones beyond $e^{v\sharp}$—a difference of 273 vibrations (exp. 31).

Other things being equal, the beats are strongest when the two tones are of equal loudness. But, as we have seen, the strength of beats is also dependent on their frequency, reaching a maximum when they are neither very rapid nor very slow; and the particular frequency which yields beats of maximum strength varies according to the tone region.

If two near tones, *e.g.* of 256 and 264 vibrations, be sounded together, it is not difficult to observe that the beats arise from the varying intensity of the sensation of a *single* tone, the pitch of which lies roughly midway between the pitch of the two primary tones. This is called the

"intertone." As the interval between the two primary tones is increased, the intertone, the pitch of which lies at first rather nearer the lower than the higher of the tones, seems to rise a little in pitch, and it becomes less evident. A *multiple* tone impression is at length produced, first the higher, then the lower, of the two primary tones emerging and becoming distinguishable as the interval is increased. Careful attention shows that it is always the intertone which carries the beats. It is of softer character than the primary tones, and is localised within the ear. When in the above example the mistuned prime reaches 300 vibrations, the intertone is almost inaudible (exp. 32).

[Sometimes the beating tone may appear to vary, not only in loudness, but in pitch. This is probably due to the prominence of overtones during the periods of relative silence, and is thus an example of the confusion of change of timbre with change of pitch (page 31).

Beats may be heard when the two tones are separately conducted, one to one ear, the other to the other. Careful experiments have been made upon these so-called "binaural" beats. Two electrically driven tuning-forks were used as the source of sound. They were placed one in each of two rooms situated on either side of a central room, in which the observer sat. The tones were led to his ear by means of sound-tight tubes, and were thus completely isolated from one another. The audibility of binaural beats was held to prove that our experience of beats is of central origin, due to the stimulation of the auditory centres by impulses travelling up the auditory nerves. This view meets with very little sympathy at the present day. All recent evidence goes to show that when two tones of nearly identical pitch are led to the two ears separately, each tone passes by bone conduction to the opposite ear, where by interference with the other tone it gives rise to beats. Auscultation of the skull roof by means of a specially constructed microphone has definitely proved that con-

duction occurs in this way. There can be little doubt that uniaural and binaural beats have the same (peripheral) origin.

Beats may be heard when the primary tones, led to separate ears, are so faint that each when sounding alone is inaudible. We shall subsequently see (page 53) that conduction from ear to ear is a possible explanation of the audibility of binaural beats from such tones of subliminal intensity.]

BIBLIOGRAPHY.

H. L. F. von Helmholtz, *Sensations of Tone*, trans. by A. J. Ellis, London, 1895. C. Stumpf, *Tonpsychologie*, Leipzig, i. ii., 1883, 1890. K. L. Schäfer, "Der Gehörsinn," in *Nagel's Handbuch d. Physiol. d. Menschen*, Braunschweig, 1905, iii. 476. A. Barth, "Zur Lehre von den Tönen und Geräuschen," *Ztsch. f. Ohrenheilkunden*, 1887, xvii. 81. F. Krüger, "Beobachtungen an Zweiklängen," *Philosoph. Stud.*, 1900, xvi. 307, 568.

CHAPTER IV

ON AUDITORY SENSATIONS[1] (*concluded*)

Combination Tones.—When two different tones, not too closely similar in pitch, are sounded simultaneously, "combination tones" are heard in addition to the two primary tones. They are localised within the ear. Combination tones are of two kinds, "summation tones" and "difference tones." The former can only be heard with great difficulty; but their existence, although from time to time denied, has been unquestionably proved by means of appropriate resonators.

The pitch of the summation tone corresponds to the sum of the vibration frequencies of the two primary tones. The pitch of the difference tone, which even the unpractised may hear without difficulty (exps. 33–35), corresponds to the difference of these frequencies. Thus, if h be the pitch of the higher and l that of the lower primary tone, $h-l$ will be the pitch of the difference tone produced when h and l are simultaneously sounded. This tone is sometimes called the first difference tone, D_1, because there are various orders of difference tones, more than one of which may be simultaneously present. For example (exp. 36), a second difference tone, D_2, may be detected, which has a pitch $2l-h$; it may be looked on as a difference tone between the lower primary and the first difference tone, $l-(h-l)$. A third difference tone, D_3, may also occur, having a pitch $3l-2h$,—a difference tone between the second and first difference tones. Even fourth and fifth

[1] See footnote at the beginning of Chapter III.

orders of difference tones, D_4 and D_5, have been detected by a trained observer. Which of these higher orders of difference tones are recognisable is said to depend principally on the interval between the primary tones.

[In investigating the nature of combination tones, we have first to ascertain whether they are of subjective or of objective origin. That is to say, we must determine whether pendular vibrations, corresponding to the pitch of the combination tones, exist in the air when the two primary tones are simultaneously generated; or whether these sensations of combination tones are of our own making, devoid of any external physical basis.

To test the independent existence of pendular waves we have recourse to resonators. If the latter picks out a tone, its objective existence is proven. Now investigations with appropriate resonators have shown that, under certain conditions, combination tones are of objective origin, while, under others, they are mainly or solely of subjective origin. The particularly favourable condition for producing objective combination tones appears to be this,—that at the moment of their generation the two primary tones must throw one and the same enclosed volume of air simultaneously into vibration.[1] For example, the combination tones produced by the tones of a siren or a harmonium, which is blown by a single wind chest, are objective. But if two separate bellows be used, so that the air supply for each primary tone is different, then, although the combination tones are hardly less audible than before, they are very largely of subjective origin; resonators will reinforce them in a far less degree. In the case of the combination tones of tuning-forks, practically no resonance is obtainable; the combination tones which we hear must be almost entirely, perhaps entirely, subjective.

Objective combination tones may be readily explained by mathematical and physical considerations; whereas the

[1] This has lately been disputed by Hermann (*op. cit.*).

interpretation of subjective combination tones has always proved a far more difficult problem. From recent experiments, however, it appears that membranes, resembling the tympanic membrane, produce objective difference tones when thrown into vibration by two simultaneous tones. If this be so, we have an obvious explanation of the origin of combination tones within the ear. The few cases that have been recorded of patients, devoid of tympanic membrane or of malleus and incus, who are yet able to hear subjective combination tones, perhaps suggest that these tones may be similarly formed at the fenestra rotunda. If subjective combination tones really arise from the vibrations of such membranes, it becomes intelligible that two tones, which are so high in pitch as to appear identical, or are altogether beyond the limit of hearing, nevertheless give audible subjective difference tones.

In order to avoid complications, it is essential that the tones, used for producing combination tones, be as pure as possible. Even tuning-forks are not devoid of overtones (page 30); but these may be removed by the use of interference tubes.[1] The most careful work upon combination tones has been done under conditions where the sources of sound are far removed from the listener, and the sounds are purified, so far as possible, by interference apparatus from any accompanying overtones before they reach his ear.

Experience has shown that weak tones are far more favourable for exact observation than strong, although earlier observers were of the opposite opinion. The primary

[1] One method of "interfering" with a tone of a given wave length is to transmit the tone through a bifurcating tube. The two arms of the fork subsequently reunite, but their lengths so differ that the sound waves, passing along the one arm are at the point of reunion in opposite phase to those passing along the other. Another method of interference is to provide the conducting tube, somewhere in its course, with one or more side tubes closed at their ends. The side tube is of such length that the waves, after entering it and being reflected at the closed end, return to the main tube in a phase opposite to that of the newly arriving waves which have not traversed the side piece.

tones should be of equal intensity, for difference tones become less evident with increasing difference of intensity of the primary tones. Sometimes, however, a different order of difference tone may be detected when the relative intensity of the primary tones is changed.

A difference tone is heard with far more difficulty when its pitch lies between that of the primary tones. A simple calculation will show that if the primary tones bear a simple relation to one another (*e.g.* 1 : 2, 2 : 3, 3 : 4), the various orders of difference tones (page 42) often coincide; and it is under these circumstances that difference tones are best heard.

The overtones of primary tones also yield combination tones with one another. Two or more combination tones and overtones may thus occur at the same moment, which are so closely similar in pitch that they fuse to produce a single beating intertone. Such beating intertones are formed even from pure (*i.e.* overtone-free) tones when consonant intervals are mistuned. For example, a tone will beat with its mistuned octave. If the first overtone be present, such beats are partly to be ascribed to the intertone formed between the higher primary tone and the first overtone of the lower primary tone. But even when the latter overtone is removed by interference tubes, beats are still audible owing to the formation of a difference tone of nearly the same pitch as the lower primary tone.

Difference tones may be heard when the primary tones are isolated and led separately to the two ears, or when one tone is led to the ear and another is communicated by a tuning-fork applied to the teeth or to the head. Under such circumstances, conduction of both primary tones to one and the same ear unquestionably takes place.

König held that two primary tones could give rise to combination tones which were neither summation nor difference tones. At one time, indeed, he denied the existence of difference tones altogether, and he gave the name of

"beat tones" to the tones which he obtained. The difficulties raised by König were the inevitable result of his employing loudly sounding tuning-forks to produce the primary tones. The relatively powerful overtones accompanying König's primary tones, and the complicated series of combination tones produced by them, were the source of the many difficulties which he raised. There can no longer be any doubt as to the existence of difference tones and the non-existence of beat tones.

The formation of the combination tones $h + l$ and $h - l$, when the air is simultaneously affected by vibrations of periods h and l, may be attributed to the periodic disturbances arising between h and l. We may thus regard objective combination tones as the result of mutual periodic disturbances in the generation of the primary tones.]

Variation Tones.—Tones of like pitch and of like formation are also produced when l is no longer a series of disturbing sound waves, but consists of a number of simple interruptions applied to h. Thus, if the tone h, issuing from a siren, be interrupted l times per second (by the closure of alternate groups of the holes in its rotating disc), the tones $h + l$ and $h - l$ will be heard in addition to the tone h. These tones are called "variation tones," and may be strengthened by appropriate resonators.

Interruption Tones.—According to the most recent views, either of these two variation tones may produce a difference tone with the primary tone. At all events, a tone may undoubtedly be heard, under suitable conditions, which has the pitch $l\ (= \overline{h+l} - h$, or $h - \overline{h-l})$. This latter tone is called the "interruption tone," its pitch coinciding with the number of interruptions given per second to the primary tone. By means of an appropriately attuned resonator, it also has been proved to have an objective existence.

[The interruption tone is best heard when its pitch is considerably different from that of the primary tone, and when the primary tone is so high that the variation tones

differ little from it, and thus are feebly audible. On the other hand, the variation tones are best heard when the primary tone is so low that the still lower interruption tone is inaudible. Like ordinary difference tones, the interruption tone is localised within the ear.

Various methods have been utilised in order to produce variation and interruption tones. If a siren be employed, the disc of which contains three series each of ninety-six holes, and if in the first series every alternate group of four holes be shut, in the second series every alternate group of three holes be shut, and in the third series every alternate pair of holes be shut,—we shall clearly be able to demonstrate three different interruption tones having vibration frequencies in the ratio $1 : \frac{4}{3} : 2$. For in the first series there are twelve interruptions, in the second sixteen, and in the third twenty-four interruptions per revolution. As there are ninety-six holes, the vibration frequency of the highest of the three interruption tones must be one-quarter (*i.e.* two octaves below) that of the primary tone.

An interruption tone may also be obtained when a card is made to press against a rapidly revolving toothed wheel, the teeth of which are at regular intervals filled up or removed. The pitch of the primary tone is determined by the total number of both closed and open teeth. The number of interruptions in the teeth determines the pitch of the interruption tone. An interruption tone is also produced when the vibrations communicated by a tuning-fork to the air are periodically interrupted by a rotating disc provided with alternate closed and open sectors.]

The Relation of Tones.—If various pairs of successively sounding tones be compared (exp. 37), a closer relation and an easier transition will be found between the members of some pairs than between those of others. The tone nearest related to a given tone will prove to be the octave or any multiple of the octave. Even practised musicians, when

asked to identify a given tone, are apt to confuse octave tones with one another.

One might at first feel disposed to express this relation throughout the tone range by means of a spiral, along which the tones are marked off in order, and successive octave tones are so placed that they overlie one another. But such a diagram would fail to represent the facts at all accurately, inasmuch as the next most nearly related members are found to be a tone and its fifth above, which would lie on such a spiral at a point furthest removed from the lower tone. After the fifth, the fourth is the next closely related interval. Then follow the major and minor thirds and the sixths.

The confusion of a tone with its octave may be also demonstrated by sounding the two tones simultaneously and asking a listener to report whether one or more tones are present. If the octave tone be weak in comparison with the lower, it is unnoticed, except in so far as it alters the timbre and the apparent pitch of the lower tone (page 31). Even when the two tones are of equal strength, a trained musician will sometimes return wrong judgments. Unmusical people experience a like difficulty of analysis in the case of other less closely related pairs of tones (exp. 38), the percentage of their wrong answers being approximately as follows:—

Octave.	Fifth.	Fourth.	Thirds and Sixths.	Seconds and Sevenths.
75	50	30	20	10

There is hence a very strong tendency for octaves, and a diminishing tendency for fifths, fourths, thirds, and sixths, to produce an apparently single tone sensation. This blending or fusion of simultaneous tones corresponds in degree precisely with the recognised order of "consonance" or agreeableness of the intervals in music. The octave is the most perfect consonance, of course excepting unison. Then

follows the fifth, next the fourth, and lastly the major and minor thirds and sixths (page 29).

The remaining intervals within the octave, *e.g.* seconds and sevenths, and the corresponding intervals beyond the octaves, *e.g.* ninths and fifteenths, are termed "dissonances." The dual nature of such simultaneously sounding tones can be recognised without difficulty even by unmusical observers; they show hardly any tendency to fusion. Want of fusion and dissonance also occurs in a most marked degree when consonant intervals are appreciably mistuned.

The Absolute Determination of Pitch.—We may be able to determine the pitch of a given tone by observing the interval between it and a previously given tone the pitch of which is already known. Or we may be able to determine the pitch absolutely, without reference to any other tone. The absolute determination of pitch is then dependent on a close association between each tone and its alphabetical name. When the tone is sounded, its name immediately appears in consciousness.

This close association of tones with their names is acquired in much the same way as the association of colours with their names, or as the association of different shades of timbre with the different voices or instruments that produce them. It is often learnt quite early in life, but it can, at least sometimes, be acquired later, and can be much improved by practice. There are great individual differences in the scope of absolute pitch determination. Of course, in the majority of persons it is entirely lacking. Some can only name a single tone, others can identify a narrow or a wide range of tones. In some persons the name of the note is not suggested directly. They need the intermediate visual imagery of the alphabet or of the keys of the pianoforte, or visual or kinæsthetic imagery of the hands or fingers moving upon the instrument.

Closely allied to, but by no means always correlated with this talent is the power to produce a tone whenever

its name is given. The exact pitch of the tone thus produced depends on the pitch of the instrument at which the individual has been musically educated. So, too, when asked to name a sounded tone, he is most accurate in his replies to the tones of the particular instrument to which he has been most accustomed. Inaccuracies occur when the tone is of unusual timbre or intensity, or when the subject is excited, depressed, or fatigued.

It is far easier for a person so gifted to say that a given tone is c, d, or e, than for him to say which particular c, d, or e is sounded. He may never confuse d' with c' or with e', but he always finds it difficult to distinguish d' from d'' or from d°. Occasionally the confusion occurs not only between octaves but between fifths, the next consonant interval.

We have no definite knowledge of the methods by which the association of tones with their names is acquired. It is, however, noteworthy that young children (and birds), when once they have been taught a short musical phrase, tend to repeat it without any subsequent alteration in pitch. This tendency is obviously favourable for a sensibility to absolute pitch, but it is soon discouraged, owing to the fact that they generally hear the same melody repeated in different keys. Sensibility for intervals replaces sensibility for absolute pitch.

The Cochlea.—So far, in speaking of auditory stimuli, we have traced their course only so far as the fenestra ovalis of the middle ear. The sound vibrations now pass into the fluid perilymph and travel to the end organs of the inner ear.

In the higher mammals the end organs of the saccule, the utricle, and the semicircular canals are predominantly, if not wholly, concerned with functions other than hearing (Chap. V.). In them the cochlea has reached its greatest complexity.

There are serious experimental difficulties in the removal

of one or other of these end organs from the vertebrate inner ear. Even when the operation has been successful, errors may arise, and have actually arisen, owing to the use of auditory tests of such loudness that the animal becomes aware of the vibrations by the sense of touch instead of by hearing. Yet such evidence as has been obtained by experimental removal of the cochlea is in favour of the view already mentioned, that in the higher mammals it is pre-eminently the organ of hearing.

Helmholtz's Theory of Hearing.—Helmholtz, observing that we have the power possessed by resonators of analysing mixtures of tones (complex periodic waves) into their simpler tonal constituents (component pendular waves), constructed a theory of hearing on the analogy of physical resonance (page 22). He supposed that the cochlea contains a vast number of differently resonating structures, each of which is attuned to a tone of definite pitch and is thrown into sympathetic vibration when the appropriate tone reaches the cochlea. The vibrations, passing up the perilymph of the scala vestibuli and down the scala tympani, are transmitted across the cochlear canal in their course. A given tone will thus cause one of the resonators of the cochlea to vibrate, leaving others untouched; and each of these others will, in turn, vibrate when a suitable tone reaches them. According to this conception, the cochlea resembles in construction the pianoforte; any string of which, as is well known, can be thrown into vibration, if the tone to which it is attuned be sounded before it. After some hesitation, Helmholtz concluded that the fibres of the basilar membrane, which number about twenty-four thousand in the human cochlea, are the resonant structures comparable to the strings of the pianoforte.

This hypothesis has met with much support in different directions, despite certain difficulties which we shall later have cause to discuss. If the evidence of an undoubtedly difficult experiment can be accepted, dogs become deaf to

high tones when the lowest whorl of the cochlea is destroyed, and to low tones when the highest whorl of the cochlea is destroyed. It has also been found that the lowest whorl of the cochlea was affected in the case of a deaf boilermaker, the noise of boilermaking being conducive to deafness, especially to high tones. Now these are just the results we should expect, were Helmholtz's theory correct; for the basilar fibres increase in length from the base to the apex of the cochlea, and it may be presumed that the shortest fibres resonate to the highest tones.

Moreover, careful examination has revealed that persons may be deaf to a few isolated tones only, or may hear only in very limited regions, throughout the tone range. These "tone gaps" and "islands of hearing," as they may be termed, receive a ready explanation at the hands of Helmholtz's hypothesis. It is easily imaginable that certain basilar fibres or groups of basilar fibres have ceased to vibrate properly, or that the hair cells and nerves, which the vibration of these fibres should stimulate, no longer behave as they ought.

Conditions have been described in which a single tone produces a double tone sensation in one ear ("uniaural diplacusis"), or is judged by one ear to have a pitch considerably different from that which it appears to have when heard by the other ("binaural diplacusis"). Such anomalies may perhaps be attributed to the disordered function of certain basilar fibres, or of the hair cells and nerve fibres supported by them.

Extensions of Helmholtz's Theory.—If the cochlea really contains a mass of variously attuned fibres, the principles of resonance require that a given tone will throw into vibration not only the fibre to which it is accurately attuned, but also neighbouring fibres which are attuned to tones very slightly higher or lower in pitch (page 23). These latter fibres will vibrate with diminishing amplitude according to their distance from the fibre to which the tone exactly corresponds.

In consequence, the effect of any given tone on the basilar membrane may be graphically represented by a wave, the apex of the wave coinciding with the most powerfully vibrating, *i.e.* the exactly attuned, fibre; on either side of which the fibres vibrate with less and less force in proportion to their remoteness. According to this conception, the pitch of a tone is determined by the position of the apex of the imaginary wave. Now, if two tones of nearly identical pitch be simultaneously sounded, these two waves will very closely overlap, and will by summation yield a single wave which has an apex somewhere intermediate between the apices of the component waves.

By this extension of the resonance hypothesis, intertones (page 40) become readily explicable. It is obvious that, as the interval between two nearly identical tones becomes greater, and as the overlapping of the two waves diminishes in extent, the apex of each individual wave must become prominent, the two tones must become separately audible, and the intertone must finally vanish. The beating character of the intertone is ascribable to the interferent action of the two series of sound waves on the same fibres.

On the same grounds, we can explain the audibility of binaural beats produced by tones of subliminal intensity (page 41). The tones are conducted to one and the same ear by bone conduction; their wave effects on the basilar fibres overlap and strengthen one another so as to produce an audible beating intertone. A nearly liminal sensation, of course, becomes more effective when intermittent.

Helmholtz's hypothesis implies that (so far, at least, as tone sensations are concerned) the apparatus of the inner ear has no concern with the actual movements of the membranes and ossicles and of the external air. The cochlea merely resolves these vibrations into their pendular constituents, utterly disregarding the complex unresolved movements of the conducting media.

If this be true, two or more simultaneously sounding

tones must produce the same tonal experience, whatever be the respective phases in which their waves are combined. The ear must take no account of the very different movements of the air, ossicles, membranes, and perilymph which result from combining the same two series of waves in varying phases relatively to one another. Many investigations have been made in order to determine whether the cochlea is affected by these differences of phase, or merely resolves the periodic curve into its pendular components. It is impossible here to review the experimental difficulties and the errors which have beset the investigation of this important question. The broad conclusion of the majority of reliable workers need only be quoted,—that differences in the phase of sound waves make no appreciable change in the experience of tone sensations.[1]

Now this view, that our experience of tones and beats is determined solely by the analytical action of resonators within the inner ear, has been opposed by many physicists and physiologists, who have believed that any regular interruptions in a tone stimulus, if sufficiently rapid, can develop a sensation of tone. There are some facts which at first sight appear to tell in favour of this belief. For example, if a tone is interrupted sufficiently rapidly, an interruption tone (page 46) is produced. Again, if the interval between two tones is not too close, difference tones are produced. In each of these cases the pitch of the tone depends on the frequency of the interruption. Further, König, as we have seen (page 46), went so far as to name difference tones "beat tones." He supposed that a number of sufficiently rapid interruptions in the movements of the tympanic membrane must give rise to a definite tone sensation; in other words, that within certain limits of rapidity every kind of periodic vibration can develop a tone sensation.

[1] The effect of binaural phase difference on sound localisation is discussed in Chapter XXI.

But such a view is irreconcilable with Helmholtz's hypothesis that only pendular vibrations can cause tone sensations. And its improbability is shown by the following considerations. If beats really pass over into difference tones, the difference tone ought not to be audible until the beats have disappeared. In point of fact, the presence of beats may still be felt when high tones are simultaneously sounded, which give at the same time an obvious difference tone. Moreover, if the first difference tone arises from rapid beats, the higher orders of difference tones and the summation tone become wholly inexplicable. As regards the interruption tone, a different and more satisfactory interpretation has been already given (page 46). There is therefore no reason, at present, to discredit Helmholtz's view that only pendular vibrations can give rise to a tone sensation.

At first believing that the sensations of noise and tone arose from separate end organs, Helmholtz thought that the saccule was the seat of noise sensations, but later he abandoned this idea. Certainly the psychological characters of noise and tone are very different (page 27), but that is not a sufficient reason for supposing that the cochlea is concerned solely with developing tone sensations. Were this so, we should expect that pathological conditions would arise, causing deafness to tones, while noises could still be heard, —or *vice versâ*. Such conditions, however, have never been recorded.

We have already explained (page 53) that according to Helmholtz's theory the pitch of a tone sensation must depend on the position of the most strongly stimulated basilar fibre. Now, let us add to this hypothesis that a sensation of noise results, when one fibre does not vibrate more strongly than the rest. Then we can account for the occurrence of noise, whether the stimulus be the simultaneous sounding of many nearly identical tones, an explosion, or a blow on the ears. For in all three conditions a considerable part of the basilar membrane is

thrown into uniform vibration, and there is no well-defined point of maximal stimulation. Such a point may conceivably be lacking, when a tone stimulus lasts for an exceedingly brief time (page 26); so that here again we meet with a reason for the development of a noise sensation.

[*Theories of Consonance.*—We may now take up the deferred problem of the basis of harmony. According to Helmholtz, the relation of two consecutive tones to one another depends on the degree of coincidence or of dissimilarity of their overtones. A given tone will therefore be most nearly akin to the octave tone following it, because all the harmonic overtones of the latter will occur in those of the former. In the case of the fifth, the one tone—which we may denote by $2n$—will produce the overtones $4n$, $6n$, $8n$, $10n$, $12n$, etc.; while the other tone, $3n$, will produce the overtones $6n$, $9n$, $12n$, etc. Here the tonal relation is less close than in the case of the octave, alternate overtones of the tone $3n$ being contained in those of the tone $2n$. Still fewer overtones will be shared by the tones of a fourth, and so on for the various intervals.

This principle, that the relation between two different tone sensations depends on the presence of identical stimuli, may be likewise traced in the further elaboration of Helmholtz's theory of hearing proposed by Ebbinghaus. He suggested that a given tone of n vibrations per second affects not only its properly attuned fibre of the basilar membrane, but also those fibres attuned to tones of $\frac{n}{2}$, $\frac{n}{3}$, $\frac{n}{4}$, . . . vibrations per second, causing them to vibrate in half, thirds, quarters . . . from 1, 2, 3 . . . nodal points respectively. According to this view, the relation between two successive tones, even when free from overtones, depends on the number of basilar fibres that the two tones stimulate in common.

There can be little doubt that musical intervals were originally chosen from successively sounding tones. Primi-

tive men played and sang in unison long before they practised polyphonic, *i.e.* many part, music. When, however, different tones began to be simultaneously sounded, new æsthetic effects, literal "consonance" and "dissonance," were produced,—due in Helmholtz's opinion to the presence or absence of beats. Certainly the absolute consonances, unison and octave, yield no beats. Fifths only give rise to beats when the higher overtones are exceptionally loud and beat with one another. Fourths, thirds, and sixths produce beats more easily. Indeed, the minor sixth (5 : 8) is on the border line between consonance and dissonance, the second overtone (15) of the lower tone beating audibly with the first overtone (16) of the higher. In dissonant intervals, the beats obtrude still more. According to Helmholtz, our judgment of consonance or dissonance in the case of simultaneous tones depends on the relatively continuous or interrupted (*i.e.* beating) character of our tonal experience.

If beating overtones determine the dissonance of intervals, it is evident that dissonance should be much less in the case of intervals which are produced by tones freed from overtones. Helmholtz and many other observers have declared this to be true, although later experiments, of a somewhat unsatisfactory nature, have been brought forward to contradict it.

More recently attention has been drawn to the effect of mistuned consonances on the pitch of the difference tones of various orders. It has been shown that in such dissonant intervals beats arise from the intertones which are formed between neighbouring difference tones and (especially the lower of) the primary tones, while in the case of consonant intervals the difference tones are free from beats and owing to their coincidence are much fewer in number (page 45).

Let us repeat, however, that pure tones are a philosophical fiction. For every tone is accompanied by one or

more overtones; and even when they are obliterated by interference, they may conceivably be re-formed within the ear before the end organ is reached. When we judge that a tone is pure, we do so because we are incapable of analysing the really complex pattern of vibration received at the cochlea: complex, because of the inevitable overtones which are simultaneously, be it ever so feebly, stimulating the appropriate end organs. Throughout our life, no tones are more closely associated with any given musical tone n, than one or more of its accompanying overtones $2n$, $3n$, $4n$, $5n$, $6n$, unanalysed though they be. And these are the very tones that form with one another the most consonant intervals. Thus harmony is seen to have a natural basis of association.

We have already pointed out (page 48) that simultaneously sounding tones of consonant intervals are with difficulty analysable. They blend smoothly with one another and fuse more or less perfectly, so that the resulting experience is or resembles that of a single tone sensation. According to Stumpf, this fusion is the psychologically irreducible criterion of consonance and dissonance. For him neither beats nor the relations of overtones constitute a satisfactory basis of harmony. But it is impossible here to enumerate or to discuss his objections.]

Criticism of Helmholtz's Theory of Hearing.—The difficulty of Helmholtz's theory of hearing is mainly one of conception. The 24,000 basilar fibres range in length only from about 0·04 to 0·48 mm. Nevertheless they are expected to vibrate to tones varying between 15 vibrations and over 20,000 vibrations per second. Compensation for such small differences in length of fibre is only possible by almost inconceivably great differences in loading. Again, it is hard to believe that the basilar fibres are free to vibrate as stretched strings. They are lodged in a homogeneous matrix, supported by connective tissue. Nor, in any event, can they vibrate along their entire length, carrying as they

do the rods of Corti and a small vein beneath the tunnel. The pars pectinata appears to be the only freely vibratile portion, but its variations in length, in different regions of the cochlea, are still less than the variations in length of the entire fibre.

We may, perhaps, ask if the power of analysing mixed tones into their constituents, closely as it resembles the phenomenon of physical resonance, may not have a far more obscure physiological basis. Whether the living protoplasm of the hair cells themselves can have this analytical property, and if so what is its nature, we are quite unable to say. But we may bear in mind that the hairs of hair cells in certain invertebrata have been observed to vibrate selectively to special tones; that the cochlea is so constructed as to permit of the ready conduction of vibrations to the hair cells; that the hairs vary in length in different regions of the cochlea; and that their vibrations are doubtless damped by the overlying tectorial membrane.

Rutherford's Theory.—Rutherford suggested that the peripheral end organs of the ear act merely as a telephone plate which receives various patterns of vibrations and transmits them by the auditory nerves to the brain, where analysis actually takes place. Such an hypothesis—unsatisfactory, if only because it pushes explanations still further into the unknown—serves to remind us that the peripheral mechanism is not the sole determinant of auditory sensation. Yet in hearing as in vision, the task of deciding how far the process of sensation is due to peripheral and how far to central factors, lies confessedly beyond us.

Ewald's Theory.—The difficulty of conceiving that the basilar membrane behaves like a series of resonating structures, led Ewald to study the actual movements of non-living membranes in response to sound vibrations. In his earlier experiments he employed an elastic membrane, which was stretched loosely in its longitudinal direction on a wooden frame, and in its transverse direction was either

held more tensely or more often was not stretched at all. A vibrating fork, when pressed against the end of such a membrane, was found to form upon it a series of waves, which were visible as dark transverse streaks or nodal lines, and could be photographed under suitable conditions. These streaks or lines were termed by Ewald "sound pictures." He found that the number of, and the distance between, successive transverse lines were determined by the pitch of the exciting tone, their number being doubled when the pitch was raised by an octave and halved when the pitch was lowered by an octave. Each tone was found to produce its peculiar sound picture; simultaneously occurring tones formed their respective sound pictures independently; noises produced a series of continuously changing sound pictures. Believing that similar sound pictures might be formed on the minute basilar membrane of the cochlea, Ewald later endeavoured to construct an artificial membrane more closely resembling it in size and delicacy. From an aluminium disc he cut out a rectangular slit about eight millimeters in length and half a millimeter in breadth. He plunged the disc in a solution of rubber in benzine, which on evaporation left a minute and extremely thin rubber membrane over the slit. The disc was then surrounded by fluid in a chamber, one wall of which was fitted with an artificial fenestra ovalis connected by a solid rod with an outer membrane representing the tympanic membrane. A beam of light was thrown on to the artificial basilar membrane, the formation of sound pictures on which was observed through an adjustable microscope, or was photographed by a camera attached to the microscope. Ewald found that such a delicate membrane would respond by giving sound pictures through a range of more than six octaves, when the artificial tympanic membrane was thrown into vibration by tones reaching it from the air. He called his chamber a "camera acustica," urging that the sound pictures produced in it veritably represent the behaviour

of that part of the cochlea basilar membrane which underlies the tunnel of Corti. Ewald's theory, that each tone produces its own sound picture on the basilar membrane, and that the tone sensation depends on the particular hair cells which are stimulated by the waves or lines of the sound picture, was at first considered to be even less probable than that of Helmholtz, until he recently demonstrated the phenomena in this way on an artificial model. Such a demonstration could not fail to advance his theory in general favour. Much more, however, remains to be done before it can be fairly weighed with the older resonance theory. We must know whether such a membrane can accurately represent the more complex structure of the basilar membrane, whether it can completely picture difference tones, how it responds to beats and to changes of phase, and how the analysis of simultaneously sounding tones into their components is conceivable. Meanwhile we can only hold a suspended judgment.

Meyer's Theory.—Another theory of hearing, dispensing with the necessity of analysis by resonators in the cochlea, may be briefly noticed. Max Meyer suggested that the loudness of a tone is determined by the extent of basilar membrane bent out according as the thrust of the stapes is strong or feeble. He suggested that the pitch of a tone is determined by the frequency with which the basilar membrane is so bent, the frequency being dependent on the number of thrusts per second of the stapes. According to this view, the individual movements of the stapes determine the sensation produced in the cochlea, a loud sensation arising when many hair cells are thrown into vibration by a single thrust of the stapes, a sensation of high pitch arising when any given hair cell is stimulated with sufficient frequency by rapid movements of the stapes. The theory, however, fails to account for difference tones satisfactorily, and would compel us to admit the influence of phase differences on auditory sensations (page 54).

BIBLIOGRAPHY.

In addition to the works mentioned in the last chapter—C. Stumpf, "Konsonanz u. Dissonanz," *Beitr. zur Akustik u. Musikwiss.*, 1898, i. 1. M. Meyer, "Zur Theorie d. Differenztöne u. d. Gehörsempfindungen überhaupt," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorg.*, 1898, xvi. 1; "An Introduction to the Mechanics of the Inner Ear," *Univ. of Missouri Studies*, Sci. Series, 1907, ii. No. 1. K. Ewald, "Zur Physiol. d. Labyrinths," *Arch. f. d. ges. Physiol.*, 1899, lxxvi. 147; 1903, xciii. 485. F. Krüger, "Zur Theorie d. Combinationstöne," *Philosoph. Stud.*, 1901, xvii. 185. K. L. Schäfer u. O. Abraham, "Studien über Unterbrechungstöne," *Arch. f. d. ges. Physiol.*, 1901, lxxxviii. 207. O. Abraham, "Das absolute Tonbewusstsein," *Sammelb. d. internat. Musikgesell.*, 1901, iii. 1. C. S. Myers, "The Ethnological Study of Music", among *Anthropological Essays*, Oxford, 1908. L. Hermann, "Neue Untersuchungen über d. Natur d. Kombinationstöne," *Arch. f. d. ges. Physiol.*, 1908, cxxii. 419.

CHAPTER V

ON LABYRINTHINE AND MOTOR SENSATIONS

The Resemblance of these Sensations.—We may conveniently consider these two classes of sensations in the same chapter, since they are both closely related to the position and to the movements of the individual. The end organs, subserving the development of labyrinthine sensations, are contained in the inner ear; the nervous impulses are conveyed by the vestibular division of the auditory nerve. The end organs, that are concerned in motor sensations, are situated in the motor apparatus.

Motor sensations are often called "kinæsthetic" sensations. But, strictly speaking, the labyrinthine sensations are likewise kinæsthetic in function.

The sensations, developed by the motor apparatus and by the labyrinth of the ear, further resemble one another in their vague and unprojected character, and in the relatively insignificant place they occupy in the field of consciousness. Moreover, the end organs of the motor apparatus and of the labyrinth are alike engaged in continuously transmitting impulses by which muscular tone is reflexly maintained and movements are unconsciously co-ordinated.

A study of these sensations impresses on us the important fact that psychology must needs take into account not merely the conscious but also the unconscious aspects of psycho-physiological processes.

Labyrinthine Sensations.

The End Organs.—The end organs of the semicircular canals, perhaps together with those of the utricle and saccule, are the seat of sensations by the aid of which we become aware of the position, and of movements, of the head. They also transmit nervous impulses, which reflexly co-ordinate the movements of the eyes, head, and body; and they aid in maintaining the tone and reflex activity of the general muscular system.

Experimental Interference with the Canals.—The effect of experimentally stimulating a single canal is to produce movements of the head in the plane of the canal stimulated. The effect of destroying a canal depends on the amount of stimulation produced during the operation. With special precautions a canal may be cut through so as to yield practically no ill effects. If, however, the corresponding canal on the opposite side be then removed, uncontrollable pendular movements of the head are set up, together with other disturbances in eye movement and in general co-ordination, which we shall consider immediately.

After removal of the labyrinth on one side, the resulting disturbance is in great part asymmetrical; it is also less obvious and more transient than the disturbance following the removal of both labyrinths. In the latter event, a most striking lack of co-ordination is brought about. The animal falls hither and thither, and spins round, often irresistibly damaging itself; its eyes are in a state of almost incessant movement. If a bird, it is unable to fly properly or to pick up its food, save with great difficulty.

In course of time, these uncontrollable movements of the head, eyes, and body begin to disappear; but for some days or weeks, there may be a loss of co-ordination and attacks of apparent giddiness, whenever movements of the head are attempted. So long as the head is at rest, the results of the operation are almost negligible. Sooner or later, this

inco-ordination and giddiness, together with other disturbances (which need not concern us here) likewise vanish; the most lasting effects of destruction of the canals consisting in a general loss of muscular tone and power, and in a diminution of reflexes.

The Mach-Breuer-Brown Theory.—It has been suggested that the end organs of the canals are stimulated by changes in pressure, due to movements in the fluid which surrounds the end organs. Upon this hypothesis, the start of any head movement must initiate a stimulus, owing to the tendency of the fluid to lag behind and so to press on the end organs of one or more canals, according to the plane of the movement. But as soon as the fluid and the end organs move with equal speed, that stimulus must cease. A fresh stimulus will occur when the movement of the head ceases, the fluid tending by its own inertia to continue in motion and thus to stimulate the now resting canals. In consideration of the microscopic calibre of the semicircular canals, this hypothesis has since been slightly modified, in detail only, but not in principle. It was urged that no appreciable movement of fluid could occur within canals the diameter of which measured in man one-tenth of a millimeter, and in birds much less. Instead of the displacements of fluid *en masse*, the wave-like action of thrusts of fluid on the end organs was accordingly substituted.

This hypothesis, brought forward by Mach, Breuer, and (in its original form only) by Crum Brown, implies that the canals are stimulated only by change from a state of rest to one of movement of the head (or *vice versâ*), or by change of rate of movement of the head. Experiment shows that this is actually the case. When an individual is passively rotated with closed eyes, he soon loses all sensation of movement, so long as the plane and the rate of rotation are constant, and so long as he does not move his head. But he at once appreciates any actual acceleration of movement; and if he move his head, the sensation of rotation, previously

lost, returns. Moreover, when the speed is retarded or when rotation is actually stopped, he is under the illusion that the direction of rotation is reversed. It is further found that, after various changes in the direction of rotation have rapidly succeeded one another, his judgments of the direction are apt to be erroneous.

Eye Movements produced by Rotation.—When the eyes are open during active or passive rotation of the body, it will be observed that at the start of rotation they fix a stationary object and then jerk forwards in the direction of rotation, that they then fix another object and again jerk forwards, and so on. These forward movements are so rapid that no account is taken of the visual sensations of movement arising therefrom. Hence to the individual, at this stage, external objects appear stationary. As rotation continues, the eyes no longer rest but passively follow the movements of the body, so that external objects now seem to be moving in a direction opposite to that of rotation. After rotation of the body has ceased, the eyes continue for some time to move involuntarily in the same direction as before, intermittently swinging suddenly back, again passively moving on and then swinging back. Objects thus appear to continue moving in the same direction as before. After rotation of the body has ceased, there is a strong and often irresistible tendency to recommence rotation.

Head Movement in Rotation.—The axis, about which external objects appear to rotate when the body has come to rest, depends on the position of the head in relation to the axis of rotation. If during or immediately after rotation the head be moved (*e.g.* if it be inclined to one shoulder or if the face be turned to the ceiling or to the ground), the body appears to be rotating in a different direction and the axis of rotation of external objects is changed.

Giddiness.—Giddiness is experienced when a galvanic current is transmitted through the ears. An illusion of falling towards the cathode pole arises, to counteract which

the subject may actually fall towards the anode pole. Giddiness is a common symptom of Menière's disease, in which the functions of the semicircular canals are unquestionably disturbed. The giddiness which ensues on rotation of the body is absent or deficient in a certain proportion of deaf mutes; this proportion being so similar to the frequency of defective canals found in deaf mutes after death, as to suggest a definite relation between giddiness and the proper function of the semicircular canals. In somewhat like proportion, deaf mutes fail to show the usual eye movements which occur during rotation of the body. They also find difficulty in walking in a straight line, in standing on one leg, or in otherwise balancing themselves, when their eyes are shut. There is thus ground for believing that the movements which occur during rotation, and that the co-ordinations which occur during rest of the head (cf. page 64), are the reflex results of stimulation of the semicircular canals; and that giddiness arises when there is a discrepancy or confusion between the various labyrinthine, retinal, cutaneous, and motor sensations which inform us of the position of the body relatively to the external world.

The giddiness which so commonly arises from sudden, and for the moment inexplicable, alterations of our surroundings (for example, when we are gazing at a mirror which is suddenly blown by the wind), while our feet and body are stationary, may be ascribed to a similar discrepancy of sensations and to a similar confusion. Giddiness is also apt to occur in any unfamiliar strain upon the eyes, for example, when strange glasses are worn and unusual binocular movements are required, or when such glasses are removed after adaptation thereto. It may occur as the result of very rapid stimulation or movements of the eyes, *e.g.* in regarding flicker, or in watching a waterfall. It occurs in disturbances of circulation and in disease of the central nervous system, and is induced by certain drugs, *e.g.*

alcohol and tobacco. In each case there is, for various reasons, a disturbance in co-ordination, manifesting itself, objectively, in disordered movements (which in part, at least, seek to repair the disturbance) and, subjectively, in the experience of giddiness.

The Utricle and Saccule.—The functions of the maculæ of the utricle and saccule are quite uncertain. It is said that the positions of the two maculæ are exactly perpendicular to one another, and that they favour horizontal and prevent vertical movement of the otoliths which they contain. And it has been suggested that their hair cells may be stimulated by the overlying plate of otoliths, giving rise to sensations which are interpreted either as change in inclination, or as translatory motion, of the head, according as the movement involves simultaneous excitation of the semicircular canals or not. But there are many difficulties in the way of accepting this hypothesis.

Motor Sensations.

In addition to having a labyrinthine origin, sensations of movement also originate in the locomotor apparatus of the body. We are aware when in the dark we have actively moved our finger, or when it has been moved for us passively; we know roughly the speed, the direction, and the extent of this movement (exps. 39, 42).

Their Non-cutaneous Origin.—It is easily demonstrable that such kinæsthetic experiences are quite independent of cutaneous sensations. In cases of locomotor ataxia, the former are to a great extent abolished while the sensibility of the skin may be unimpaired. With their eyes shut, such patients may be unaware whether or to what extent their limbs have been actively or passively moved; they are unable accurately to co-ordinate their movements, or to estimate the position of or the resistance offered to their limbs. In normal individuals, the skin may be anæsthetised

by the application of cocaine or by a faradic current, and yet the kinæsthetic sensations are as acute as, if indeed not more acute than before (exps. 40, 41).

The End Organs.—These sensations of movement conceivably originate in muscles, tendons, or joints. They are indeed often called "muscular" sensations, from a long-standing belief that they are produced by excitation of the sensory structures (*e.g.* muscle spindles) which are contained and excited within the contracting or relaxing muscles. Various reasons, however, have been advanced in favour of the view that these sensations are chiefly of articular origin. In the first place, some muscles, *e.g.* the long flexors and extensors of the digits, lie at a considerable distance from the joints on which they act and at which we localise the resulting movements; these muscles being connected to the bones by very long tendons. Secondly, it has been found that the smallest perceptible movement is approximately the same for passive as for active movement. Both arguments obviously lack cogency: the former because it leaves out of account the influence of the tendons, the latter because it overlooks the changes in form or tension of these, and their antagonistic, muscles during passive extension or flexion. Such changes might lead to excitation of the contained sensory organs.

Of greater weight is the observation that a faradic current, when passed through a joint, raises the threshold for active or passive movement considerably. Thus, whereas under ordinary conditions a movement of the first inter-phalangeal joint can be just perceived when it is passively moved through an angle of 0°·5, it has been found that the threshold is raised to 1°·5, 2°·5 or even to 3°·85 (according to the strength of the current), when a current is passed through the joint during movement. The movements of the finger produced under these conditions, especially when the eyes are closed, are described as jerky and inco-ordinated, like those of an ataxic patient (exp. 44).

In support of the articular source of kinæsthetic sensations, attention has also been called to the imperfect sense of movements and of position possessed by jointless organs, such as the lips, the tongue, and the eyeballs, when the contributing aid of tactile or visual sensations is excluded (page 278). Moreover, in certain cases of locomotor ataxia, the kinæsthetic sense has been found to become still blunter by pulling the joint surfaces apart from one another. It seems reasonable, then, to conclude that articular sensations are a very important determinant of our awareness of movement.

Characters of Kinæsthesis.—In our everyday movements, the attention is primarily concerned with the aim of the intended movement, or with the general situation of which it forms part; we are but dimly conscious, or often quite unconscious, of the kinæsthesis itself. Such sensations of movement as we have are supplemented and greatly obscured by visual experiences. It is only when new movements are being carried out, or, more especially, when prescribed movements are made with the eyes closed, that the true nature and importance of kinæsthesis are appreciable.

Under such conditions it is easy to demonstrate that there are three directions in which sensations of movement may vary, namely, in extent, duration, and quality. The kinæsthesis in a short movement is obviously less extensive than that in a longer movement. The kinæsthesis in a slowly moving limb lasts longer than that in a more rapidly moving limb. The kinæsthesis in the toe or elbow is of different quality from that in the finger or shoulder. It is difficult to see how sensations of mere movement can be more or less intense; but other forms of motor sensation (cf. page 71) are clearly characterised by intensity.

Illusions of Extent of Movement.—The duration of kinæsthesis is one of the factors underlying our estimation of the range or extent of movement. A slow movement

appears longer than a rapid movement of the same range. Our estimation of the range of movement is also dependent on the relation between the duration of movement and the degree of muscular effort put forth.

Other Motor Sensations.—When we come to consider our appreciation of weight, we shall find reason to believe that our awareness of muscular effort depends on two other classes of motor sensations,—sensations of deep pressure and sensations of strain or tension, which are principally of muscular and tendinous origin (exp. 43). We may note, in passing, that sensations of movement, deep pressure, and tension by no means exhaust the list of sensations yielded by the motor apparatus. We have, for example, sensations of cramp, residing in the muscles, sensations of fatigue, doubtless common to muscles, tendons, and joints, and the articular sensations of friction and of contact, which occur during active or passive rotation of joints and during sudden shocks or jars.

Other Factors determining Extent of Movement.—When, in the blindfold subject, the arms start from a symmetrical position (the mid-line of the body), and simultaneously execute intentionally equal and similar movements (*e.g.* the right arm moving to the right, the left arm to the left), these movements are usually unequal. One of the subject's arms habitually travels the farther: that is to say, he underestimates the extent of its movement. Probably, as a rule, the preferred arm executes the longer movement,—the right arm in right-handed, the left in left-handed individuals. But this is not invariably the case; for the subject may make allowance for the readier movement of one arm, and, indeed, may make excessive allowance. A further complication may arise from the fact that, of two movements, that which requires or receives the more attention, tends to be overestimated, the corresponding kinæsthetic experience being the more marked.

When the arms move successively, instead of simul-

taneously, the two movements are much more nearly equal. In this case the task is easier, as the attention is now undivided.

It is generally believed that when two movements are successively carried out by the same group of muscles, that movement tends to be the greater which is effected by the initially less contracted muscle. For example, if the arm make two successive, intentionally equal, downward movements, that movement is the longer which is begun in the more downward position of the arm. This explanation, however, is for several reasons unsatisfactory. For, if a whole series of successive and apparently equal movements are executed by the arm (moving from right to left or from above downwards), it appears that both the initial and the terminal movements are overestimated relatively to the intermediate movements.

We have to bear in mind that our appreciation of the muscular effort put forth, upon which, as we have said, our estimate of movement in part depends, is invariably the result of activity, not in a single muscle, but in a group of muscles. The degree to which different muscles are involved in the movement of a limb varies widely in different stages of its excursion. Towards the completion of a prescribed movement (as in lifting the arm above the head), fresh muscles may be brought into action, which were not engaged at the start of that movement.

We have, therefore, to take into account the total experience of muscular effort put forth; we cannot state the error of estimation in terms of the degree of contraction of a single muscle. The overestimation, met with in the initial and final portions of a subdivided arm movement probably finds its readiest explanation in the relatively greater ease and freedom with which the intermediate series of movements is made. In the extreme positions of an arm, a greater force of muscular contraction is necessary; and this greater exertion produces the illusion of more extensive

movement. Similarly, inasmuch as the leg habitually executes freer and more extensive movements than the arm, the leg actually moves through a wider range than the arm, while to the blindfold subject they appear to execute equal movements (exp. 44).

Awareness of Position.—It might be thought that our appreciation of movement is dependent on our appreciation of change of position. But we have indications that such a comparison of positions does not necessarily take place. The effect of transmitting an electric current through a joint is to obliterate awareness of position, while awareness of movement (although much more obtuse than in the absence of faradisation) is still preserved. The movement of a finger may be recognised when it is of so slight a duration (an extremely small fraction of a second) that it is difficult to suppose that any discrimination between a series of positions has taken place. In the third place, a passive movement may be recognised, and yet the direction of movement and hence the nature of the change of position may be doubtful (exp. 42).

There is, indeed, more reason to think that our awareness of position is dependent on that of movement than that the reverse relation holds. When our limbs are screened from the eyes, and are kept unmoved for a considerable time, or if they be passively moved while our attention is distracted, we find great difficulty in determining their position without moving them.[1] In awakening from sleep, we are confronted with a like difficulty. But while movement greatly aids our judgment of position, the latter is unquestionably in part dependent on what we may term "statæsthetic" sensations, that is on sensations which, having presumably the same origin as kinæsthetic sensations, are developed during rest of the mobile organs. Our sense of position is further clearly dependent on that complex series of earlier visual,

[1] Recent experiments, however, throw doubt upon the general truth of this statement.

tactile, and kinæsthetic experiences, the sources of our conception of form and space.

Comparison between the Nervous Connections of the Motor and Labyrinthine Sensory Apparatus.—It may be worth while, before we close this chapter, briefly to compare the connections which the afferent motor and vestibular nerves respectively make with the central nervous system.

A voluntary (skeletal) muscle is controlled, in the first place, by a lower system of "nuclear" nervous arcs, the centres of which lie in the sensory cells, and in the cells of the motor nuclei, of the spinal cord, bulb, and mid-brain. The efferent parts of these nuclear arcs consist of the cells of the motor nuclei, together with their axis cylinders, which terminate in the end plates of the striated muscular fibres. Their afferent parts are derived from peripheral sensory nerve fibres which run from various muscular, tendinous, cutaneous, and other tissues towards the sensory cells, to terminate ultimately around the cells of the motor nuclei.

This system of nuclear arcs is, in turn, controlled by higher series of arcs, situated in the cerebral hemispheres, in the cerebellum, and possibly elsewhere. The centres of the cerebral "cortical" arcs lie in the cells of the sensory and motor cortex. Their efferent parts consist of these cortical motor cells, and of their axis cylinders which descend in certain columns of the mid-brain, bulb, and cord, terminating around the motor nuclei. Their afferent parts come from muscular, tendinous, cutaneous, and other structures, ascending within the cord, and (with the aid of relays) passing to the cerebral cortex. Probably the cerebellar arcs have a similar constitution.

Finally, higher systems of arcs exist, overlying and co-ordinating the above systems.

The vestibular nerve resembles in its cerebellar connections those of the afferent nerves of the motor apparatus: its relation to the cerebral cortex is little known. The

cerebellum is the great centre where afferent impulses, alike from the labyrinthine and motor apparatus, are gathered together. From the cerebellum efferent impulses proceed to the fore-brain and to the mid-brain, bulb, and cord, influencing the discharge of impulses along the efferent neurons of the nuclear arcs.

BIBLIOGRAPHY.

A. Crum Brown, "On the Sense of Rotation," etc., *J. of Anat. and Physiol.*, 1874, viii. 327. E. Mach, *Grundlinien d. Lehre v. d. Bewegungsempfindungen*, Leipzig, 1875 ; *Contributions to the Analysis of the Sensations*, Eng. trans., Chicago, 1897. J. Breuer, "Ueber d. Function d. Otolithenapparate," *Arch. f. d. ges. Physiol.*, 1890, xlviii. 195 ; (with similar title), *ibid.*, 1897, lxviii. 596 ; *Sitzungsber. Wiener Akad. d. Wissensch.*, *math.-nat. Cl.*, 1903, cxii. Abt. 3, 315. A. Goldscheider, *Gesammelte Abhandlungen*, Leipzig, 1898, ii. V. Henri, "Revue générale sur le sens musculaire," *L'Année psychologique*, 1899, 5me Année, 399. R. S. Woodworth, *Le Mouvement*, Paris, 1903. W. Nagel, "Die Lage-, Bewegungs- und Widerstandsempfindungen," in *Nagel's Handbuch d. Physiol. d. Menschen*, Braunschweig, 1905, iii. 735. W. Peters, "Die Bewegungs- u. Lageempfindungen," *Arch. f. d. ges. Psychol.* (Literaturbericht), 1905, v. 42. E. Jaensch, "Ueber d. Beziehungen von Zeitschätzung u. Bewegungsempfindung," *Ztsch. f. Psychol.*, 1906, xli. 257. C. Spearman, "Die Normaltäuschungen in d. Lagewahrnehmung," *Psychol. Stud.*, 1906, i., 388.

CHAPTER VI

ON VISUAL SENSATIONS[1]

The Characters of Visual Sensations.—Our visual sensations comprise colourless and colour sensations. The series of colourless sensations include every shade of grey between the most blinding white and the deepest black (exp. 45). Colour sensations include not only the various "spectral" hues which are afforded by the analysis of daylight, but also others which are not to be thus obtained, *e.g.* purple and carmine. They differ in hue (or colour), intensity, saturation, and brightness.

The normal (or "adequate") stimulus to the retina is a series of wave movements in the surrounding ether. The various hues, seen in the spectrum, are dependent on the different lengths of these waves, sensations of red being excited by the longest, those of the violet by the shortest ethereal waves. But, as we shall see presently, these (and other) hues are also obtainable by appropriate mixtures of ethereal waves.

The intensity of a colour (or colourless) sensation is dependent on the intensity of the stimulus, *i.e.* on the amplitude of the light waves which fall upon the retina.

The saturation of a colour sensation is dependent on the amount of white light that simultaneously excites the same retinal area (exp. 46). The spectrum affords, with less difficulty, more highly saturated sensations than any other external source of stimuli.

[1] See footnote to Chapter III.

When highly saturated colour sensations, *e.g.* those yielded by the spectrum, are compared, they obviously differ among one another in brightness. Under ordinary conditions of vision, yellow is the region of maximal "brightness value." Brightness is a psychical character which is distinct from intensity and saturation. Unlike these, it has no obvious physical correlate (exp. 47).

We shall soon be in a position to realise that these four characters of colour sensation, hue, intensity, saturation, and brightness, are determined not merely by the nature of the stimulus, but also by the condition of the cerebro-retinal apparatus at the time of stimulation.

[Our colour sensations in everyday life are greatly influenced by previous knowledge. We come to ascribe an *absolute* colour to all familiar objects, and we either wholly neglect occasional variations in their colour, or else treat them as chance modifications of an underlying absolute colour. We unconsciously make allowance for, and hence fail to observe, such differences in shade as experience has taught us to expect under different conditions of illumination (exp. 48). When, on the other hand, we are forced to notice the altered colour of a well-known object,—when, for example, we behold the rosy glow shed by the setting sun on a snow mountain,—we cannot resist the interpretation that we are looking at a really white surface accidentally reddened by the peculiar illumination under which it is viewed; for this reason we tend to underestimate the degree of redness of the snow. Nor are such innate tendencies dispelled by the fullest conviction that the hue is determined both by the nature of the object and by the nature of the illumination under which the object is viewed.]

The Conditions of Colourless Sensations.—A colourless sensation may be produced by re-combining all the spectral colours obtained by the analysis of white light. It may also be produced by combining merely three colours in appropriate proportions, provided that they are properly

chosen. Three such colours are called the "primary" colours. They may be represented as occupying the angles of a triangle (fig. 1, page 82), along two of the sides of which may be marked off spectral colours that are intermediate in wave length between those at the angles. It is possible to produce any colour sensation, by mixing these three colours (if necessary, with black and white) in other proportions (exp. 49).

Within this triangle a point W may be found, which will yield a white sensation when a straight line is drawn through that point between any points on opposite sides of the triangle. That is to say, every colour has a corresponding colour which, when presented simultaneously to the same retinal area, produces a colourless sensation. Such colours are called "complementary" to one another (exps. 50, 51).

[It might be expected that the hue of a colour stimulus would become more intense, the greater the intensity of the stimulus. But, beyond a certain limit, further increase of the intensity of the stimulus causes the corresponding colour sensation to pass over gradually into a colourless sensation. Indeed, any colour stimulus, if sufficiently intense, is seen as white. Intense spectral reds and orange, and greens up to a wave length of 517λ,[1] acquire a yellow hue before they in this way become colourless. A green, of a somewhat shorter wave length than 517λ, can be found, which passes over into white without change of colour tone. Intense colour stimuli, of still shorter wave length, become blue before they become colourless.]

Under certain conditions, all colour stimuli, if sufficiently feeble, become reduced to the colourless (black-white) series. Conversely, all feeble colour stimuli produce, under suitable conditions, a colourless sensation, and, as they become stronger, yield a colour (or "chromatic") sensation. The conditions of this so-called "photochromatic" interval will be discussed later.

[1] λ signifies a millionth part of a millimeter.

The photochromatic interval appears upon diminution of a colour stimulus in extensity, as well as in intensity. That is to say, when the retinal area stimulated by the colour is sufficiently small, a colourless instead of a colour sensation is developed.

All colour stimuli appear colourless at the extreme periphery of the normal retina. They are seen as shades of grey, the depth of grey depending on the brightness of the colour and of the background on which it is seen. Within this outermost retinal zone of total colour blindness is an intermediate zone of red-green blindness, where only blue and yellow sensations are developed. The innermost zone is the region of normal or complete colour vision. It is more correct to speak of these as zones of colour weakness rather than as zones of colour blindness, inasmuch as their limits vary with the intensity and extent of the colour stimulus (exp. 52).

Colour stimuli, when acting for a long period on the retina, gradually fail to produce colour sensations. When, for example, coloured glasses are continuously worn, external objects are sooner or later seen in their natural colours. It can be shown that the normal eye is similarly "adapted" to the reddish light which enters the retina through the sclerotic and iris (cf. exp. 132). Upon removal of a colour stimulus to which the retina has been adapted, an after-sensation of the complementary colour is developed.

Successive Contrast.—If, after having carefully fixated a coloured patch, the eyes are closed or are turned to fixate a larger uniform surface, the form of the coloured patch shortly appears as an "after-image." According to the conditions of the experiment, this after-image will have the same brightness and the same hue as the original presentation, or it will have the opposite degree of brightness and the complementary hue. Indeed, by projecting the after-image on to surfaces of appropriate hue or brightness, any desired hue or brightness of the after-image may be obtained.

The fixation of such a coloured patch under ordinary conditions (as described in exps. 53–55) results in an after-effect, or, more strictly speaking, in a series of after-effects, the hue and brightness of which are complementary to those of the original sensation. These are effects of "successive contrast." They are termed "complementary after-sensations," or, more loosely, "negative images." We shall defer our consideration of what have been called "positive" after-images and of their relation to these negative images until later.

[We have spoken of a series of after-sensations, rather than of a single after-sensation. For the after-image comes and goes, recurs, and again disappears; and this happens several times before the after-image vanishes altogether. The number and duration of such fluctuations are said to depend on the shape, size, and duration of the original stimulus, and upon the steadiness of fixation while the after-effects are being observed. Very large and very small after-images fluctuate little, if at all. The influence of movements of the eyes upon the steadiness of after-images has been the subject of much controversy. Some observers believe that involuntary eye movements are an important, if not the principal, cause of the fluctuation of after-images. Others deny that such movements are essential, insisting that periodicity is an inherent character of the after-image process. In support of the latter view, it may be pointed out that movement of the background causes disappearance of the after-image no less than movement of the eyes, and that, if two different patches are successively fixated so as to yield two near-lying after-images upon the retina, not only are the fluctuations occurring in the one, not simultaneous with those occurring in the other after-image, but this want of synchronism is undisturbed by movements of the eyes.

The complementary effects, obtained from a given retinal area after the removal of its stimulus, may be also

obtained during continued fixation, by diminishing the brightness or saturation of stimulus.]

Simultaneous Contrast.—Phenomena, analogous to those of successive contrast, also occur owing to the influence which neighbouring areas of the retina exert upon one another; they are effects of "simultaneous contrast." For example, a given patch of grey or of colour tends to be tinged in the colour complementary to that stimulating the rest of the retina; this is known as "colour contrast" (exps. 57–60).

Further, a dark colour or a grey becomes brighter or darker, according as it lies on a background darker or brighter than itself; this is known as "brightness contrast" (exps. 61–63).

Brightness contrast is particularly well marked at the adjoining margins of the two contrasting areas. It subserves the important biological function of sharply outlining the borders of seen objects.

Colour contrast becomes more evident, the more nearly the sensations are of equal brightness, and the more completely any differences in texture and the like are obliterated between the contrasted surfaces (exp. 59).

Both brightness contrast and colour contrast are intensified by increasing the extent or saturation of the stimulus that evokes the contrast effect.

[*Simultaneous and Successive Induction.*—But these effects of contrast disappear on prolonged fixation and are replaced by others of a directly opposite character. The surface, which at the beginning of fixation had evoked a contrast colour or brightness, now induces its own colour or brightness. This is termed "simultaneous induction." Corresponding changes in the after-image are termed "successive induction" (exp. 74).]

Spectral Colour Mixtures.—We have seen (page 78) that three primary colours can be chosen, which by admixture in various proportions will give rise to colourless sensations

and to colour sensations; and not only to the colour sensations given by the spectrum, *e.g.* orange, yellow, and blue, but also to those not so given, *e.g.* purple and carmine. The three colours which we shall represent at the corners of the colour triangle (fig. 1), are red, green, and violet. Other colours might have been chosen instead of these, but one of them would necessarily have been a purple or carmine, and would thus not have obtained representation in the spectrum.

If two different colours, lying towards the red end of the spectrum, be thrown simultaneously on the retina, the resulting sensation is indistinguishable from the sensation which would have been aroused by a colour stimulus having a wave length intermediate between them. Thus a given red and a given yellow stimulus, when mixed, produce just the same orange sensation as an orange spectral light would have produced. The sensation resulting from this mixture becomes more orange-red or more orange-yellow, according as the red or the yellow stimulus preponderates in intensity over the other. Thus the effects of mixing colour stimuli at this end of the spectrum may be compared to weighting a lever at its ends and finding its centre of gravity.

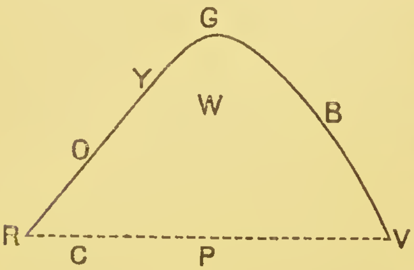

FIG. 1.

Such conditions, however, hold only when that of the two colours which is the more remote from the red end, is not greener than a certain yellowish-green, or more precisely when its wave length does not fall below 540λ. Beyond this point, the effect of mixing such a colour with a red is to produce a sensation of gradually diminishing saturation; until ultimately a green is reached which, when mixed with the red, produces a colourless sensation. The

curvature about the apex of the triangle (fig. 1) indicates the turning-point, where this diminishing saturation begins to occur.

The curvature of the line between green and violet similarly indicates that a mixture of green and violet spectral lights yields a less saturated blue sensation than would be given by the intermediate blue spectral light; in other words, the resulting sensation lies nearer the point marked W. The effect of mixing spectral red and violet is to produce carmine or purple colour sensations, according to the preponderance of the red over the violet or of the violet over the red stimulus.

Colour Blindness. — There are three fundamentally different forms of congenital colour blindness, namely, red-green blindness, yellow-blue blindness, and total colour blindness. In the first the subject confuses reds and greens. This is by far the commonest form of colour blindness, its frequency among the male population in most European countries being about 4 per cent. It is seldom met with in women. The other two forms of colour blindness are far rarer, particularly the yellow-blue form (exp. 64).

There are two important classes of red-green blindness In the one the spectrum appears of the same length as in normal vision. In the other the red end of the spectrum appears distinctly darker than usual, so much so that the extreme red is not visible at all. These two classes have been respectively called the "photerythrous" and "scoterythrous" varieties. They appear to be quite distinct from one another, no intermediate or transitional cases being met with.

In the photerythrous class the point of maximal brightness of the spectrum is nearly the same as for the normal individual. In the scoterythrous class, on the other hand, it lies distinctly nearer the green.

In mixing the red end of the spectrum with various

other regions to produce a match with some third colour, the two classes are found to differ very distinctly in the amount of red which they employ, the scoterythrous requiring very much more red in their matches than the photerythrous class. Further, while the photerythrous class closely agrees with the normal individual in the grey which he chooses to match a given colour in the most peripheral ("colour-blind") zone of the retina, to the scroterythrous class the colours at the red end of the spectrum appear of an abnormally dark grey in peripheral vision.

Both classes, however, agree in seeing in the green of the spectrum a "neutral band," that is, a region which they match with a grey. They likewise match the complementary colour of this green (a bluish red) with grey.

A red-green blind person differs from the normal in that for him may be found two (instead of three) colours, by combining which (with black and white) in various proportions, a valid match may be obtained with any other colour. That is to say, the diagram corresponding to fig. 1 is for him not a triangle but a straight line.

The totally colour-blind individual sees the spectrum as a colourless band differing in brightness. There appear to be at least two classes of total colour blindness, in one of which the region of maximal brightness is in the yellow as in normal vision, while in the other the region of maximal brightness is in the green. In many cases an "absolute central scotoma" has been found in colour-blind individuals of the latter class; that is to say, they are totally blind at the fovea.

[Colour blindness may be acquired owing to the prolonged action of coloured light on the retina, or owing to the influence of drugs (*e.g.* nicotin, santonin) or of disease. Acquired colour blindness may be general or it may be confined to relatively large or small areas of the retina. Usually red and green are the first colours to be lost. Santonin, however, produces a shortening of the violet end

of the spectrum, while objects appear violet in dark and yellow in blue light. The phenomena of acquired colour blindness differ in many important respects from those of congenital colour blindness. They require further study before they can be employed to throw light on the nature of the latter or on colour vision generally.

Certain people, although not in the above sense colour blind, have "anomalous" colour vision. They may differ from normal people in their greater susceptibility to adaptation and contrast with respect to certain colours; in their hesitation when giving a name to certain colours; in requiring to see certain colours at a shorter distance from the eye, and in a state of greater saturation and intensity. Anomalous colour vision may be revealed when such individuals are asked to match mixtures of a spectral red and yellowish greens with a spectral yellow; some using very much more green, others more red than normal individuals.]

Flicker.—When a stimulus, applied to a given retinal area, is repeated with adequate frequency, an uninterrupted visual sensation is produced. The sensation corresponding to each individual stimulus always outlasts the latter, so that when the intermittent series of stimuli is sufficiently rapid, a fused and continuous sensation results. Such fusion may be studied on the colour wheel (exp. 65). [It is found that within certain limits the speed of rotation, necessary to extinguish flicker and to produce complete fusion, varies with the brightness value of the stimulus and with the intensity of illumination. The brighter a colour sensation, or the more intense a colour or colourless sensation, the greater will be the number of revolutions (*i.e.* the number of intermittent stimuli) necessary to produce fusion. Colours which are increased in brightness value, owing to dark adaptation (page 87) or owing to contrast (page 81), similarly require a more rapid intermission for the production of fusion. Observers are not agreed as to the influence

of the relative duration of the periods of stimulation and non-stimulation upon the point of extinction of flicker.

When a white sector upon a black ground is very slowly turned on the colour wheel, a series of black bands in the form of radii may be observed on that part of the white surface which first stimulates the eye. These are known, after the name of their first observer, as Charpentier's bands. With somewhat more rapid rotation, especially under bright illumination, various colours, called Fechner's colours, may be visible on the white surface. They have been attributed to the unequal action of white light on the elementary systems of cerebro-retinal colour apparatus, so that the coloured components of the white sensation make their appearance at different moments.

Two kinds of flicker can be roughly distinguished, before the point of complete fusion is reached,—a "coarse" and a "fine" flicker. The former has at certain speeds a glittering character, the brightness of which considerably exceeds that of the continuous sensation.]

When flicker is once extinguished, further increase in the rate of rotation of the colour wheel produces no change in the character of the sensation. The brightness of the fused sensation, upon the extinction of flicker, is (within certain limits) equal to the total brightness of the individual stimuli, if it be imagined that this total brightness is reduced by being uniformly distributed over the periods of excitation and non-excitation. This is the Talbot-Plateau law (exp. 66).

[*Determinations of Brightness.*—The brightness of a colour sensation may be determined by comparing it with a colourless sensation. The comparison may be made (i.) directly, (ii.) at the periphery of the retina, or (iii.) by the flicker method. There are other modes of determining brightness, but the above yield results which are fairly consistent with one another (exps. 47, 67, 68).]

The Intrinsic Light of the Retina.—The visual ex-

perience that is obtained when the retina has been for a short time completely shielded from external stimulation is very far from being identical with that of blackness. A greyish light is seen, which has been termed "the intrinsic light of the retina." We shall later (page 106) have reason to question the appropriateness of the name. Several writers have given full accounts of the intrinsic light, with slight individual variations. But as it is so easy for every one to experience and to study the condition himself (exp. 69), a detailed description is unnecessary here.

Purkinje's Phenomenon. Rod Vision.—The different brightness of colours and their photochromatic intervals (page 78) are closely connected with one another. If an observer, standing in a dimly lighted room, regard several transparent patches of different colour, which are placed on one of the walls, and if these colours be illuminated by light transmitted through apertures in the wall from an adjoining room, he will notice that the relative brightness values of the different colours change, as the intensity of the colours is decreased by diminishing the transmitted illumination. The colours belonging to the red end of the spectrum will appear relatively darker, those of the blue end brighter, while the region of maximum brightness will pass from the yellow to the green. This change of relative brightness is known, after the name of its discoverer, as "Purkinje's phenomenon." If the colours be still further reduced in intensity, they lose their hue and finally give rise merely to colourless sensations. In this stage, Purkinje's phenomenon is most marked; colours at the extreme red end being so dark that they are invisible, while the region of maximal brightness is in the green (exps. 69, 70).

If, however, the observer stands in a brightly lighted room while the intensity of the colours, illuminated by light that is transmitted through the wall, is being gradually changed as before, neither Purkinje's phenomenon nor the photochromatic interval is to be observed. The colours

retain their hue and preserve their relative brightness to one another until they are too faint to give rise to any experience but black. Thus Purkinje's phenomenon and the photochromatic interval depend not merely on the intensity of the colour stimulus, but also on the condition of adaptation of the retina. They are absent in a retina exposed and hence adapted to bright light; they are to be obtained only from the dark-adapted eye. That this adaptation is due to changes in the retina and not to changes in the size of the pupil may be proved in various ways; for example, by the persistence of Purkinje's phenomenon and the photochromatic interval when the pupillary muscles have been paralysed by atropin, and by the fact that Purkinje's phenomenon and the photochromatic interval are absent when the area of retinal excitation by the coloured areas is limited to the fovea (exp. 71).

The absence of Purkinje's phenomenon and of the photochromatic interval at the fovea, when taken in conjunction with the absence of rods at the fovea, suggests that while the cones are concerned with ordinary vision under conditions of bright adaptation, it is the function of the rods to develop colourless sensations in the dark-adapted eye. On this supposition, the rods become the end organs of colourless vision for dim light.

Now it is interesting to note that the visual purple, which the rods contain, is bleached most rapidly by green but is relatively unaffected by red light; that this visual purple is bleached far more speedily than it is regenerated; and that the bleaching in one eye is found to have no effect on the condition of the visual purple in the other eye. Corresponding with these observations, we find that green gives rise to the brightest, red to the darkest colourless sensation in the dark-adapted eye; that change of adaptation from darkness to brightness is immeasurably more rapid than the converse change; and that changes in the adaptation of one eye have no effect on the state of adapta-

tion of the other eye. Further, the rods and the visual purple are especially developed in almost all animals that live underground or are nocturnally active.

We are thus able to account for that class of total colour blindness (page 84) in which an absolute central scotoma is present, and the different parts of the spectrum appear of the same relative brightness as in the case of the normal dark-adapted eye. In these cases there is almost invariably a well-marked intolerance of bright light (photophobia), and usually there are irregular oscillatory movements of the eyes (nystagmus). All four defects, the total colour blindness, the central scotoma, the photophobia, and the nystagmus, may be ascribed to the inaction of the cone apparatus. The individual relies solely upon the rods which are adapted for use in twilight, and are absent at the fovea, the usual region for most favourable vision and steady regard.

[*The After-effects of Momentary Colour Stimuli. The Positive After-image.*—This view, that the rods of the retina are the end organs concerned in twilight vision, and that they develop only colourless sensations, was first put forward by Schultze, and has been since developed to its present form chiefly by König and von Kries. The theory gains striking support from observations on the after-effect of momentary colour stimuli. When the eye is adapted to dim light, a momentary colour stimulus produces a single colour sensation which is attended by a succession of after-effects, namely, a series of fluctuating after-sensations of the same hue as the stimulus, followed by a series of fluctuating colourless after-sensations. All these after-sensations fluctuate in the sense that each waxes and wanes, rising to a maximum and then declining, the maximal rise being less and less for successive members of the series. The coloured after-sensations are doubtless due to the persistent activity of the cones after the stimulus has been removed. The colourless after-sensations are clearly due to a similar,

but more sluggish, after-action on the part of the rods, since they are absent at the fovea, are brightest with a green stimulus, and are so dark as to be absent with a red stimulus.

These fluctuating after-sensations are followed by a continuous steady after-sensation, which is grey in the case of the dark-adapted eye (save with red and at the fovea, when it is absent), but which to the bright-adapted eye appears in the same hue as the original sensation. This is known as the "positive after-image," and is generally attributed to a persistent activity of the once excited retinal area.

The separate after-effects of the cones and rods, which have just been described, require special apparatus and experience for satisfactory observation. But the more steady and lasting positive after-image may be observed without difficulty (exp. 72).

When the eyes are closed or placed in darkness, after they have fixated, for not too long a period, a white patch, a positive after-image is obtainable, provided that the background on which the patch has rested be not too dark, and that the margins of the surface be not too sharply defined. If these conditions are not fulfilled, a halo surrounds the after-image, and the latter is dark or "negative" in character (exp. 54). Moreover, the after-image of a bright object, *e.g.* the sun, becomes positive or negative, according as the ground on to which it is projected is darker or brighter than itself. A similar reversal is said to occur in the case of coloured after-images. Under certain conditions they appear to be positive or negative according as they are projected on to a black or on to a white (or grey) background. Thus we see that a very close relation exists between positive and negative after-effects. But further experimental evidence is necessary before we can determine this relation more precisely.

Before a coloured or colourless positive after-image

disappears, it often passes through different colours. This play or "flight" of colours is doubtless due to the complex nature of our visual sensations, which are each the resultant of more elementary processes. The after-effects of these components vary in duration, and hence produce the coloured waning of the positive after-image (exp. 72).]

BIBLIOGRAPHY.

H. von Helmholtz, *Handbuch d. physiologischen Optik*, 2te Aufl., Hamburg, 1885–96. E. Hering, *Zur Lehre vom Lichtsinne* [1872–4], Wien, 1878; *Grundzüge der Lehre vom Lichtsinn* (offprinted from the *Handbuch d. Augenheilkunde*, 2te Aufl.), Leipzig, 1905, in course of publication. [A fairly complete bibliography of Hering's papers on visual sensation is given in Sanford's *Experimental Psychology*, Boston, 1897, 179, 180]. Lord Rayleigh, "Experiments on Colour," *Nature*, 1881, xxiv. 264; 1882, xxv. 64. A. Charpentier, *La lumière et les couleurs*, Paris, 1888. J. von Kries, *Über d. Funktion d. Netzhautstäbchen, Ztschr. f. Psychol. u. Physiol. d. Sinnesorgane*, 1895, ix. 81; *Theoretische Studien über d. Umstimmung d. Sehorgans*, Freiburg, 1902; "Die Gesichtsempfindungen" in Nagel's *Handbuch d. Physiologie d. Menschen*, Braunschweig, 1904, iii. 109. Shelford Bidwell, "On Subjective Colour Phenomena attending Sudden Changes of Illumination," *Proc. Roy. Soc. Lond.*, 1896, lx. 368; "On Negative After-images, and their Relation to certain other Visual Phenomena," *ibid.*, 1901, lxviii. 262. C. S. Sherrington, "On the Reciprocal Action in the Retina," etc., *Journ. of Physiol.*, 1897, xxi. 33. W. H. R. Rivers, "Vision," in Schäfer's *Text-Book of Physiology*, Edinburgh and London, 1900, ii. 1026. A. Tschermak, "Über Kontrast und Irradiation," in Asher and Spiro's *Ergebnisse d. Physiologie*, Wiesbaden, 1903, Abt. 2, ii. 726. W. Wirth, "Fortschritte auf d. Gebiet d. Psychophysik d. Licht- u. Farbenempfindung," *Arch. f. d. ges. Psychol.* (Literaturbericht), 1903, i. 21; 1905, v. 1, 77, 149. W. M'Dougall, "The Sensations excited by a Single Momentary Stimulation of the Eye," *Brit. Journ. of Psychol.*, 1904, i. 78. J. W. Baird, *The Colour Sensitivity of the Peripheral Retina*, Washington, 1905.

CHAPTER VII

ON VISUAL SENSATIONS[1] (*concluded*)

The Young-Helmholtz Theory of Colour Vision.—The Young-Helmholtz theory, first proposed by Thomas Young and later advanced by Clerk Maxwell and especially by Helmholtz, rests on the sufficiency of three standard colours, variously combined, to produce colourless and all colour sensations (page 78). It was first supposed that three distinct sets of nerve fibres exist, each of which is specially sensitive to waves of a certain length. But in the more modern form of the theory, the three sets of nerve fibres are usually replaced by three photochemical substances; and it is supposed that the first apparatus[2] is most sensitive to a carmine red, *i.e.* a red bluer than the extreme red of the spectrum, that the second is most sensitive to a slightly yellowish green, and that the third apparatus is most sensitive to an ultramarine blue. All colour stimuli are considered to act on all three systems of apparatus, but in different degrees; red colours acting most on the first, least on the last, blue colours acting most on the last and least on the first, while both these colours act, less strongly than green, on the second apparatus. The sensation produced depends on the relative extent to which the three systems of apparatus are stimulated. When they are all three

[1] See footnote to Chapter III.

[2] It must be understood that no evidence is available for determining the seat of the various processes, or of the various systems of apparatus, which have been posited in the different theories of colour vision. The processes may be partly of retinal and partly of more central, *e.g.* subcortical, origin.

highly stimulated, the sensation of white results. When they are stimulated in other proportions, other sensations, *e.g.* sensations of yellow and violet, result. The theory is thus the result of applying to the cerebro-retinal apparatus the features embodied in the eolour triangle (fig. 1).

Complementary after-sensations were attributed by Feehner and Helmholtz to fatigue, their colour being due to the subsequent over-action of the apparatus which, during the applieation of the stimulus, had reeeived a weaker stimulus. Aecording to this explanation, a grey ground is seen as green after fixation of a red surface, beeause, the red apparatus being most fatigued, the grey stimulus exeites more powerfully the remaining two systems of the eolour apparatus. When the eoloured after-image appears during elosure of the eyes, the result is similarly attributed to the affeetion of the intrinsie light of the retina (page 86).

The effects of simultaneous eontrast reeeived at Helmholtz's hands the following strained psychologieal explanation. A grey pateh on a green surfaee becomes tinged with rose, beeause, imagining that a part of the green surface is transparent so that the grey is seen through the green, the observer knows that a colour must be reddish in order that it may appear grey when transmitted through green. This knowledge is supposed to have been based upon previous experienee, and to be applied uneonsciously to the eonditions of the experiment.

The seoterythrous elass of red-green blindness was attributed by Helmholtz to absenee of the red apparatus, the photerythrous elass to absenee of the green; and the rare eases of yellow-blue blindness have been held to depend on absenee of the blue apparatus.

Hering's Theory of Colour Vision.—Hering's theory is based (i.) upon the seemingly "elementary" nature of red, yellow, green, blue, white, and black, when all the possible visual sensations are earefully eonsidered by introspeetion,

and (ii.) upon the relation of the complementary colours to one another. He assumes that there are two elementary systems, one of which gives rise to red and green, the other to yellow and blue sensations, and that there is a third apparatus, excitation of which gives rise to the colourless series of sensations. According to this theory, the physiological actions of a colour stimulus and of its complementary colour stimulus are antagonistic. Red, for example, causes a katabolic (or dissimilation) change in the red-green apparatus, yellow a like change in the yellow-blue apparatus; green causes an anabolic (or assimilation) change in the former apparatus, blue a like change in the latter. The sensation of orange results from katabolism in the red-green and the yellow-blue apparatus, that of purple from katabolism in the former combined with anabolism in the latter apparatus.

Each apparatus always tends to recover equilibrium, upon the removal of the stimulus. After the red-green apparatus has been made to undergo dissimilation owing to the "allonomous" action of a red stimulus, it proceeds to return to equilibrium by an "autonomous" process of assimilation, thereby developing the complementary after-sensation of green. Thus one colour sensation automatically evokes the opposite or complementary after-sensation.

Hering explains the effects of simultaneous contrast by a similar principle. He supposes that the process of assimilation, set up by a stimulus in one part of the retina, brings about a process of dissimilation of the same apparatus in neighbouring parts of the retina.

According to Hering, the series of grey sensations are not to be considered (as they are in the Young-Helmholtz theory) merely as different stages in the intensity of excitation of one and the same sensation, white. Hering insists that, introspectively, greys have a two-dimensional (a black-white) relation, being compounded of two variables, pure black and white, in different ratios.

He insists that black is a positive sensation no less than white. And he points to the intrinsic light of the retina (page 86) as evidence that blackness is not the condition of an absence of retinal stimulation. He calls the brightness of the intrinsic light the "sensation of mean grey." In this condition of equilibrium, the white-black apparatus may be stimulated to undergo dissimilation and to produce a brighter grey or a white sensation; and, after the removal of the stimulus, it will undergo assimilation, developing a darker grey or a black after-sensation. But in such a condition of the white-black apparatus, it can only be stimulated to undergo assimilation owing to successive or simultaneous contrast.

[Hering attributes the bright halo, which under certain conditions surrounds complementary after-images (exps. 54, 74), to a process of "successive induction." When, for example, a white square, upon a black background has been for some time fixated, the assimilation process, which, according to Hering, has been especially active just beyond the contrasting edges of the white square, reaches such a height that finally a process of "simultaneous induction" is set up; assimilation gives way to dissimilation. When now the eyes are turned away from the white square, this dissimilation process continues. It is owing to this successive induction that a bright halo appears around the dark after-image of the white surface. And the dark after-image results from the contrasting assimilation process, which is evoked by the dissimilation process that produces the halo.

The dark halo, which under other conditions surrounds an after-image, is attributed by Hering to the effect of simultaneous contrast. Thus, when a black square has been fixated upon a white background, the bright after-image of the former is produced by a subsequent process of assimilation which evokes a simultaneous dissimilation process in the adjoining retinal region.

Hering ascribes the positive after-image, produced by

closing the eyes after gazing at a bright object (*e.g.* the sun), to exhaustion of assimilation material during fixation. In consequence of this, no assimilation is subsequently possible, and all that remains is a feeble process of dissimilation due to internal stimulation.]

Hering distinguishes three states of equilibrium, which the antagonistic processes of assimilation and dissimilation may attain. The first occurs in the resting eye, and it is called "autonomous equilibrium at mean potential." It is during the return to this neutral condition that complementary after-sensations are produced when the eyes are closed. The other two states of equilibrium are brought about by adaptation to a continuous stimulus (page 79 and exp. 74). The assimilation, produced, for example, by a constant blue stimulus, becomes so reduced that it is ultimately met by an equal degree of dissimilation change in the same apparatus. Hering terms this condition of adaptation "allonomous equilibrium at high potential." The expression "allonomous equilibrium at low potential" is similarly applied to the condition of adaptation, produced by a continuous red or yellow stimulus, the dissimilatory action of which is supposed to be ultimately counterbalanced by an equivalent assimilatory action in the same apparatus. When under these conditions the stimulus is removed, the complementary sensation develops, owing to a return from allonomous to autonomous equilibrium.

Hering considers that the state of normal adaptation of the eye is the direct result of allonomous equilibrium; the white-black apparatus, for example, is continually being acted upon throughout the day. Dissimilation is most active in sunlight, less active indoors. But in each condition the apparatus soon attains a condition of allonomous equilibrium, at low or high potential, owing to the ultimately compensating effect of the opposite assimilatory process.

Hering supposes that the red-green apparatus is missing in red-green blindness, the yellow-blue apparatus in yellow-

blue blindness, while in total colour blindness the white-black apparatus alone remains. He attributes the vision characteristic of the peripheral retina to similar conditions.

He supposes that the brightness of a colour sensation is due, partly to the action of the colour stimulus on the white-black apparatus, and partly to the "intrinsic" or "specific" brightness contributed in different degrees by the two systems of colour apparatus. Under ordinary conditions, all colour stimuli act not only on one (or more usually on both) of the two systems of colour apparatus, but also on the black-white apparatus. The condition of dark-adaptation, however, permits of little or no "specific" contribution towards brightness from either system of colour apparatus. Under these circumstances, only the white-black apparatus, which is now in a condition of equilibrium at high potential, is stimulated. On the other hand, with increasing illumination, the anabolically active colours, red and yellow, contribute more and more positively, the green and blue more and more negatively, to the total brightness value, owing to their specific action on the colour apparatus. The theory attempts in this way to explain the Purkinje phenomena.

The four "fundamental" colours, chosen by Hering, are the purest red, yellow, green, and blue, which can be attained by introspection. He points out that, in reality, spectral red appears yellowish to an observer, and that the truest red is obtained by mixing with the former a small amount of blue light. According to Hering, spectral red has a not inconsiderable action on the yellow-blue apparatus. And a mixture of spectral red and green produces the sensation of yellow, because, although the red and green processes neutralise one another, the effect of the spectral red stimulus on the yellow-blue apparatus remains.

The fundamental colours thus obtained are, significantly, found by Hering to be precisely those which, when passed from the periphery to the centre of the retina, yield sensa-

tions that undergo no alteration in hue (exp. 52). The fundamental red and blue agree with the recent determinations made by adherents of the Young-Helmholtz three-colour theory; the green in the latter being somewhere intermediate between Hering's fundamental yellow and green.

Criticism of these Theories.—At the present time the majority of those who hold to a three-colour theory admit the impossibility of retaining Helmholtz's suppositions that complementary after-sensations are due to fatigue; that the effects of simultaneous contrast are of purely psychological origin; and that partial colour blindness is due to the mere absence of one or other of the three systems of apparatus.

Against the fatigue hypothesis of complementary after-sensations the following objections may be ranged. Complementary after-sensations may be obtained after extremely short periods of fixation, and are as vivid in young subjects, or after a night's rest, as in the old, or after the day's fatigue. Further, they are surprisingly bright during closure of the eyes after fixation, when they are seen merely against the grey ground of the intrinsic light of the retina. To explain why the brightness of a part of the intrinsic light should be greater than that of the whole, Helmholtz once again had recourse to psychological factors; holding that the image appears so bright, because, in the absence of any basis of comparison, we judge the general light of the retinal field to be unduly dark. Lastly, we are able to obtain after-sensations, which are equal or superior in saturation and brightness to a sensation of like hue (exp. 56).

Any psychological explanation of simultaneous contrast must obviously be of a most unsatisfactory nature. It is sufficient to point out that brightness contrast affects the point of extinction of flicker (page 85), and that in experiments upon binocular colour contrast, two differently

coloured fields, seen by separate eyes simultaneously, induce different contrast colours in the two eyes (page 281). In the latter case, one can hardly suppose that unconscious inferences from previous experience can be carried so far as to lead simultaneously to two different errors. On the other hand, it is clear that psychological influences cannot be altogether neglected (exp. 58). They appear to be of the same nature as those, arising from previous experience, to which we have already drawn attention in the preceding chapter.

There are good reasons for disbelieving that partial colour blindness is due merely to the absence of one or other of the three systems of colour apparatus. For it is generally recognised that the white sensations of the red-green blind are identical with those of the normal eye. Again, we have evidence which goes to show that the colour sensations of the red-green blind correspond to the yellow and blue of the normal eye. A case of unilateral red-green colour blindness is on record, in which the colour sensations of the affected eye were found to correspond to the yellow and blue of the normal eye. We are therefore compelled, if we retain the Young-Helmholtz theory, to give up the idea of the absence of one of the components in partial colour blindness. We must suppose that partial colour blindness is due to abnormal changes either in the relative sensitivity of the three photochemical substances to rays of different wave length, or in more central processes initiated by the excitation of these substances.

Those who uphold the trichromic (three-colour) theory of Young-Helmholtz at the present day fully realise these difficulties, and beside it admit a number of auxiliary theories. For example, they rightly feel it impossible any longer to deny that colourless sensations, under conditions of dark-adaptation of the retina, are the expression of activity in an altogether distinct apparatus.

[Rollet has suggested, and in this country McDougall has

independently elaborated, a theory of simultaneous contrast, in order to escape from the difficulties involved in Helmholtz's explanation. This theory attributes simultaneous contrast to the inhibitory action of a given cortical visual process upon the visual processes in neighbouring cortical regions. If, for example, a grey surface be fixated which has a red square upon it, the cortical area excited by the red only differs in activity from that excited by the grey (according to Helmholtz) in that the red apparatus is far more powerfully stimulated in the former. The theory, now introduced, supposes that the highly excited activity of this "red area" depresses the activity of the red apparatus in the neighbouring "grey area" of the cortex, whereby the blue and green in the latter area predominate over the red apparatus. McDougall supposes that such inhibition is due to a drainage of nervous energy from less active (or inactive) into more active regions,—a hypothesis which needs stronger physiological support before it can be accepted. We shall again mention it (page 320) when we come to deal with the process of attention. It is owing to this supposed inhibition of the red that the contrast blue-green colour is produced.

McDougall further suggests that all after-images are primarily due to the decomposition of certain retinal mother substances by the light rays, and to the persistence and stimulating effect of the unknown substances resulting from such decomposition. He supposes that the retinal nerve endings, excited by these latter substances, differ in sensitivity under different conditions and in different areas of the retina, and that fatigue may occur not only in these nerve endings, but in the corresponding cortical regions. On the basis of these suppositions, he has established a very complex theory, which, he believes, can satisfactorily account for the peculiar relations between positive and negative after-images, indicated in his numerous experiments. It may be added that he attributes the phenomena of simultaneous induction (page 81) to the diffusion of the above-

mentioned stimulating products of retinal decomposition into neighbouring retinal areas.]

Unsatisfactory as is the Young-Helmholtz theory in its original form, it must at the same time be admitted that Hering's theory is by no means free from difficulties. There are many who find it inconceivable that a sensory experience should be produced by assimilation changes in living substance. Even those who accept Hering's views as to the elementary nature of the sensations yellow and white, and as to the relation of colourless and colour sensations under ordinary conditions of illumination, feel it impossible to reject von Kries's theory of rod vision in the dark-adapted eye; they have had either to discard or to consider as inadequate Hering's theory of the specific brightness of colours.

Others, again, refuse on the following ground to place the black-white series of sensations on the same physiological basis as the red-green or the yellow-blue. Between the black and white there exists every transitional shade of grey, whereas between the yellow and blue or between the red and green obviously a very different relation subsists. When the red-green or the yellow-blue apparatus is in equilibrium, no colour sensation results, but when the white-black apparatus is in equilibrium, a sensation of grey occurs.

The shortening of the red end of the spectrum in the scoterythrous form of red-green blindness was ascribed by Hering to unusually slight pigmentation of the macula and of the lens. For various reasons, however, this explanation is unsatisfactory; partly owing to the difficulty of accounting for the absence of cases of colour blindness which are intermediate in degree between the scoterythrous and the photerythrous varieties.

Hering's explanation of positive after-images is likewise very far from satisfactory. We have already drawn attention (page 90) to the possibility of reversing a positive

after-image (*i.e.* making it negative), if its brightness be less than that of the background on which it is projected.

[*Contrast in a Smoothly Graded Disc.*—It is not easy to see how Hering's explanation of simultaneous contrast can account for the effects observed when a star of white paper, mounted on a larger black disc (fig. 2), is rotated on the colour wheel. After the extinction of flicker, a central white disc is seen surrounded by a zone of grey, which gradually darkens towards the periphery, shading into a deep black. Between the white centre and the beginning of the grey zone occurs a band of greater brightness than that of the former; while between the outer edge of the grey zone and the surrounding black occurs a band of deeper blackness than the latter.

Fig. 2.

To such conditions of smoothly graded contrast McDougall has applied the hypothesis of "drainage" (page 100). By virtue of their central nervous connections, he supposes that the more intensely stimulated cerebro-retinal elements drain away to themselves the energy from the less intensely stimulated; so that the final effect, in a disc of the above pattern, is to depress the excitation effect where the grey meets the black, and to exalt it where the grey meets the white.

This hypothesis, however, appears of somewhat doubtful validity. It must needs be proved that the two bands occur, when such a graded disc is prepared objectively, instead of being produced subjectively by rotating the black and white disc of figure 2. Moreover, when a photographic negative is taken of the latter rotating disc, it shows the same bands as the disc presents to the eye. The phenomena are therefore

perhaps connected with those of flicker, and in that case require a simpler, physical explanation.]

The Nature of "Black."—This subject has excited considerable controversy. It must be remembered that, according to the Young-Helmholtz theory, black is experienced during a state of absolute inactivity in the three primary colour systems, while, according to Hering's theory, it is the result of assimilatory change in the black-white apparatus. The difference between these two views indicates the turn which the controversy has always taken. Is our experience of black dependent on the quiescence of the cerebro-retinal apparatus, or is it a sensation which is fundamentally comparable to sensations of grey or white?

We have seen that when, in the absence of all external stimulation, the eye is in a state of dark-adaptation, an experience not of black but of the so-called intrinsic light of the retina results. We may now go further, and state that black is only experienced when an area of the retina, previously excited by white light but now unexcited by external stimuli, is in a state other than that of dark-adaptation. Thus, when first we enter an absolutely dark room after quitting daylight, the retina is as yet unadapted to darkness; hence black is experienced. Similarly, when a black image is received on a given area of the retina, so long as the rest of the retina is stimulated by light, that area can never reach a state of complete dark-adaptation; hence, again, black is experienced. A pure black results, as we have said, if the surrounding region of the retina is being stimulated by white light. If coloured light is exciting it, we should expect the black to be tinged, owing to simultaneous contrast, in the complementary colour. The effect of such tingeing, although unnoticed during excitation, may be very obvious in the after-image (exp. 60).

But if black is an experience depending on the temporary, local or general, condition of the cerebro-retinal apparatus, we are surely justified in placing it on the same footing as

those other visual experiences which, as the outcome of external stimulation, are admitted to be sensations. Were our experience of visual sensations dependent solely on the presence of external stimuli, it is, of course, obvious that no sensation could arise in the absence of a stimulus; and that therefore it would be impossible to regard black as a sensation. But the effects of successive and simultaneous contrast forbid such a view. We have repeatedly seen that the presence, the nature, and the course of a visual sensation depend not merely upon the outward stimulus, but also upon the local and general condition of the entire cerebro-retinal apparatus. It is in no way absurd to regard this local or general condition as acting in the form of an internal positive or negative stimulus upon the cerebro-retinal area under consideration. We are thus brought to the conclusion that, although there is no outward stimulation corresponding to the experience of black, there are cerebro-retinal conditions or inward stimulations, upon the existence of which the experience of black is dependent.

We seem all the more justified in regarding black as a "sensation," when we compare the effects of simultaneous and successive contrasts obtainable from black, white, grey, and from colour stimuli; when we consider the behaviour of black in binocular mixture and binocular rivalry (page 280); and especially, when we bear in mind the striking changes produced by mixing a given colour with black or with white. For example, the sensation of brown cannot be obtained by reducing the intensity of a yellowish-red spectral light or of the light reflected from a yellowish-red pigment. The result of such a reduction is that the yellowish-red more and more nearly approaches black. In order that a brown sensation may be obtained, the stimulus effect of the yellowish-red light must be "blackened" by simultaneous (exp. 62) or by successive (exp. 55) contrast, or the pigment must be mixed with black.

It is clear, then, we cannot accept as adequate Helm-

holtz's statement that we call an object black which reflects no light when light falls upon it. Such a condition is experimentally unattainable. Moreover, an object can transmit to the eye a relatively considerable amount of light, and yet, owing to contrast, it may appear black. Nor does the total withdrawal of retinal stimuli produce the experience of black. "To be blind" and "to see black" are two very different things.

[*Other Theories. General Criticism.*—More and more strongly the conviction is forced upon us that visual sensations are of a far more complex nature than Helmholtz's or even Hering's simple colour theories would lead us to suppose. Evidence is gradually accumulating that, before a sensation reaches its full development, it undergoes a process of complicated elaboration, of the details of which, however, we are as yet totally ignorant. This elaboration doubtless takes place at different stages, at different nervous levels in the cerebro-spinal system, and it is quite conceivable that stimuli, which react peripherally on separate neural elements, overlap in their action on more central elements, and that the direction of this overlapping differs at different levels. As psychologists, we are by now far removed from the crudities of the earlier physicists, who supposed that a wave of given length on reaching the retina immediately becomes transformed into a sensation of colour, and that psychical effects are identifiable with their external physical causes.

In conformity with this view, G. E. Müller has supposed that, in addition to four chromatic retinal "processes," red, yellow, green, blue, at the periphery, there are six more central "values," the red process exciting the red, yellow, and white values, the yellow process exciting the yellow, green, and white values, the green exciting the green, blue, and black, and the blue process exciting the blue, red, and black values. He supposes that a yellow stimulus excites the red and yellow processes, thereby exciting the red,

yellow, green, and white central values, of which the red and green neutralise one another. Müller endeavours to account for the varieties not only of colour blindness, but also of anomalous colour vision (page 85), by the absence of one or more of the retinal processes or of their central values or of both processes and values together.

In an earlier paper, Müller had substituted the conception of reversible chemical or molecular actions for Hering's antagonistic processes of assimilation and dissimilation. He also posited an additional cortical or sub-cortical white-black apparatus, although accepting Hering's threefold (red-green, yellow-blue, white-black) apparatus for the periphery. In the same paper Müller supposed that the central white-black apparatus determined the character of the various members of the white-black series and the brightness of colour sensations. According to this view, the more peripheral white-black apparatus, in the absence of the central white-black apparatus, is able to produce only black or white, never grey. The so-called intrinsic light of the retina, Müller urged, is really of central origin due to the activity of the central apparatus. This hypothesis is supported by the fact that even in optic atrophy and after extirpation of the eye, the so-called intrinsic light remains.

Attempts have been made to hold a position intermediate between that of Helmholtz and Hering. Donders supposed that a trichromic (red, green, and violet) system existed at the periphery of the cerebro-retinal apparatus, while a fourfold, red, yellow, green, and blue, process occurred at the centre. Like Müller, Donders assumed that a single peripheral process might act on more than one central process.

Similarly von Kries, while advocating a trichromic process, suggests that at the periphery of the retina a four-colour process is also involved.

We have already seen, in the case of temperature sensations, that a theory, which fairly represented the facts of

contrast and adaptation, became difficult of acceptance upon the discovery of a differentiation of end organs at the periphery. Contrast, however, may occur even when, as in taste, the sensations have apparently independent structural bases at the periphery. Hering's theory of contrast does not, therefore, preclude the elaboration of sensations from peripheral elements, which are different from and more primitive than those advocated in his colour theory. Nay, nothing is more certain than that, in addition to the peripheral processes of adaptation and fatigue, central processes of inhibition and augmentation occur. But at present we are powerless to separate the one from the other; we can only speak of changes in one vast unravelled complex,—the cerebro-retinal apparatus.]

BIBLIOGRAPHY.

In addition to the works mentioned in the last chapter—F. C. Donders, "Über Farbensysteme," *Arch. f. Ophthalm.*, 1881, xxvii. 155, 255; 1884, xxx. 15. F. Hillebrand, "Über d. spezifische Helligkeit d. Farben," *Sitzungsber. d. Wien. Akad. d. Wissensch.*, 1889, xcviii. Abt. 3, 70. G. E. Müller, "Zur Psychophysik d. Gesichtsempfindungen," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, x., 1896, i. 321; xiv., 189–, i. 161; "Die Theorie. d. Gegenfarben u. d. Farbenblindheit," *Bericht über d. I. Kongress f. exp. Psychol.*, Leipzig, 1904, 6. W. M'Dougall, "Some New Observations in Support of Thomas Young's Theory of Light and Colour Vision," *Mind*, 1901 (N.S.), x. 52, 210, 347; "Intensification of Visual Sensation by Smoothly Graded Contrast," *Journ. of Physiol.*, 1903, xxix. p. xix. J. Ward, "Is 'Black' a Sensation?" *Brit. Journ. of Psychol.*, 1906, i. 407.

CHAPTER VIII

ON GUSTATORY AND OLFACTORY SENSATIONS

Their Close Relation.—Taste and smell are so similar and so closely associated in experience that they may be conveniently considered in the same chapter.

The majority of substances that are said to "taste," owe their flavour to our sense of smell. If, while the nostrils are held, small pieces of apple and onion are alternately chewed, it is impossible to distinguish them. But when the nostrils are opened and currents of air permit the vapours of the apple or onion to pass up behind the soft palate into the nose (by way of the posterior nares), the two objects are at once distinguished. It is chiefly by this path that flavours reach the olfactory end organs on which they act, the nostrils serving for the examination of odours before they are taken into the system. We restrict sensations of taste to those which are produced by stimulation of the taste buds of the tongue and of adjacent tissues.

Gustatory Sensations.

Simple and Complex Tastes.—The early classifications included many tastes (*e.g.* dry, astringent, pungent, oily, and acrid) which we now recognise to result from excitation of the end organs not of taste but of touch, temperature, etc., which are contained in the tongue. The true primary tastes are sweet, bitter, salt, and sour (or acid). The insipid, metallic, and alkaline tastes are

compounded, as we shall see, from gustatory, tactile, and other elements.

Sweet and bitter substances give purer sensations of taste than salt and sour substances. Thus, a slightly burning sensation may be detected, when the tongue is treated with a solution of common salt which is too weak to give rise to a salt taste. Extremely weak acid solutions give rise to an astringent sensation, which, with increasing strength of the solution, finally passes over into pain. The true acid or sour taste may be separated from the astringent effect which accompanies it, by painting the tongue several times with a 5–10 per cent. solution of cocaine. Cocaine first abolishes the sour taste, and after several minutes begins to abolish the astringent action of the acid solution. Later the sour sensation begins to return while the astringent effect is still in abeyance, so that the application of an acid solution at a certain stage during recovery enables the true taste character of sour to be differentiated.

Sweet and bitter tastes, although much freer, are by no means entirely divorced from tactile or similar concomitants. Weak solutions of bitter substances give a "fatty" sensation, while sweet solutions when too weak to give a taste are smooth and soft, and when very intense they prick or burn. These concomitant sensations of touch, temperature, etc., may also be studied by applying the solution to tasteless regions of the mouth, *e.g.* to the hard palate.

By mixing strong solutions of salt and sweet substances in certain proportions, the alkaline taste may be nearly imitated. It has been suggested that the metallic taste is due to the simultaneous development of salt and sour tastes. The failure to produce exact alkaline and metallic tastes synthetically is in part due to the difficulty of imitating the tactile and other sensations with which they are bound up.

The Chemistry of Tasting Substances.—The differences in action of the various taste stimuli are in great part the

expression of differences in their molecular composition and constitution. Slight changes in the constitution of the molecule are sufficient to convert many sweet-tasting into bitter-tasting substances. The elements which enter into combination to give sweet compounds lie, for the most part, midway between extremely positive and extremely negative elements, when the elements are ranged according to the periodic law.

The Region of Taste.—Sensibility to taste is spread more widely over the mouth of the child than over that of the adult. The middle region of the tongue is incapable of producing taste sensations in the adult, but in the child both this area and also the mucous membrane of the cheek are efficient. In the adult, sensations of taste cannot be evoked from the lips, cheek, gums, and uvula, but they can be obtained from the soft palate, the posterior wall of the pharynx, the laryngeal surface of the epiglottis, and even from the larynx itself.

The function of the taste buds of the upper surface of the soft palate and of the larynx is altogether obscure. It has been suggested that they are the source of the sensations of certain so-called "olfactory tastes," *e.g.* the sweetness of chloroform, the frequent bitterness of ether vapour, when taken in by the nostrils. They may, on the other hand, be the onto- and phylo-genetic remains of the wider distribution of taste buds which obtains in childhood and in lower vertebrates. Possibly they serve to reinforce the reflexes that protect the laryngeal cavity from contact with food.

It is generally believed that taste sensations can be obtained only by stimulation of taste buds. In the tongue the buds lie in the circumvallate and fungiform papillæ, and it is only in these situations that stimulation of the tongue produces sensations of taste. Some of the fungiform papillæ seem incapable of yielding any taste sensations. Other papillæ are sensitive to two or three of the four classes of taste stimuli, while a few may be found which only

respond to a single class of stimulus, *e.g.* to sugar, salt, or tartaric acid; apparently no papillæ are ever sensitive solely to bitter stimuli (exp. 75).

The Action of Drugs.—The differentiation in function of the end organs of taste is shown not only by punctiform exploration, but also by the specific action of certain substances, notably cocaine and gymnemic acid (exps. 76, 77). Both act deleteriously, chiefly on the end organs for bitter and sweet tastes; cocaine abolishing especially the bitter taste, and gymnemic acid abolishing especially the sweet, leaving the other two tastes almost or quite unaffected.

Compensation, Rivalry, and Contrast.—While strong solutions of sweet and salt substances simultaneously applied to the same area of the tongue, give rise to an alkaline taste, with weak solutions of these substances the corresponding sensations tend to be neutralised. Unless a very small part of the tongue is tested, it is apparently impossible to arrive at an absolutely indifferent stage. Generally, when the compensation between the two antagonistic tastes is complete, an insipid taste results. Some observers, however, claim to be able to reach an absolute zero. The compensation of tastes,—the partial abolition of sourness in wine or of bitterness in coffee by sugar,—is familiar to us all. The best examples of compensation appear to occur between sweet and salt, the worst between sweet and sour tastes.

Rivalry between two simultaneously present tastes may occur; but usually, where compensation is absent, a qualitatively new experience arises in which analysis may detect the component elements (exp. 78).

Contrast effects may be obtained between any two of the four taste sensations, save bitter. Some individuals, especially those whose sensitivity to tastes is obtuse, fail to obtain them. The contrast may be so contrived as to be either simultaneous or successive. The easiest obtainable contrast sensation is usually sweet; it may be evoked more

readily with an inducing salt than with an inducing sour stimulus. Thus, the (simultaneous or successive) contrast effect of salt is to make distilled water taste sweet, while solutions of sugar, previously too weak to produce a sensation, are now tasted as sweet (exp. 79).

We are wholly ignorant of the physiological and psychological nature of compensation, rivalry, and contrast in taste. Many writers have attributed them to central rather than to peripheral factors. Indeed, so long as we suppose that the four primary tastes are dependent on *four distinct kinds* of end organs, it is at first sight difficult to refer compensation and contrast to peripheral conditions. The same difficulty confronted us in dealing with visual sensations (page 107).

On the other hand, we must bear in mind that we are still wholly ignorant of the sub-cortical connections which the peripheral nerve fibres, subserving the development of taste sensations, may form with one another. Further, we cannot reject the alternative view that the four primary tastes are the result of four different modes of reaction in *one and the same* end organ, some end organs being capable of reacting in all four, others in less than four modes; a view which gains some support from the fact that no cases are on record of individuals in whom only one taste is wanting and the others are normal.

Olfactory Sensations.

The Conditions of Smell.—Odours are emitted owing to the vaporisation of substance, the odoriferous vapour disseminating by diffusion from its source to the nose. The olfactory epithelium in man occupies a very small area of the nasal mucous membrane, and is normally bathed in fluid. In unhealthy conditions of the nose which involve increase or decrease of the surrounding mucus, the sensitivity of the olfactory epithelium is seriously affected.

Experimental evidence, although somewhat conflicting, favours on the whole the view that odoriferous substances must reach the region of the olfactory membrane in gaseous form in order to produce their smell. We can but dimly conjecture how these gaseous particles stimulate the hair-like processes of the sensory end organs. It has been suggested that the olfactory stimulus consists in intramolecular vibrations, yielding ethereal waves of such extreme shortness, that they are lost even in the thinnest layers of air, and that hence it is essential for the odorous particles to come into close contact with the epithelium. According to this view, the nature of the olfactory sensation is determined by the character of the intramolecular vibrations, which is in turn dependent on the nature and mode of grouping of the atoms within the odorous molecule.

To a limited extent it is certainly true that substances which are chemically related emit similar odours. The elements chlorine, bromine, and iodine, and the compounds of sulphur, selenium, and tellurium, are examples of this broad principle. Practically all the odorous elements belong to the fifth, sixth, or seventh group in the periodic system of classification. In addition to these elements, the organic compounds form an important group of odorous bodies. A study of the changing nature and intensity of the odour of members of the series of fatty acids or of fatty alcohols, affords instances of the relation between odour and chemical constitution. On the other hand, it is not difficult to find substances of widely different constitution which are strikingly similar in smell.

Classification of Smells.—In the other senses which we have studied, we have endeavoured first to determine the number of elementary sensations by introspection, and then to find out how far experiment and observation in health and disease justify us in recognising these sensations as primary, and in regarding each of them as the resulting activity of a different specific apparatus. It is, of course,

difficult to construct on an introspective basis a system of classification of smells which shall be generally acceptable; but the following scheme, suggested by Zwaardemaker, imperfect as it is, may serve as an example:—

I. *Ethereal smells.*—(*a*) Fruit ethers. (*b*) Beeswax. (*c*) Ethers, aldehydes, ketones (lower members of homologous series).

II. *Aromatic smells.*—(*a*) Camphor. (*b*) Spicy smells. (*c*) Anise and lavender. (*d*) Lemon and rose. (*e*) Almond smells.

III. *Balsamic smells.*—(*a*) Jasmine, ylang-ylang, orange blossom. (*b*) Lily-like smells. (*c*) Vanilla smells.

IV. *Amber-musk smells.*—(*a*) Amber. (*b*) Musk smells.

V. *Allyl-cacodyl smells.*—(*a*) Sulphuretted hydrogen, asafœtida and like smells. (*b*) Fishy smells. (*c*) Halogen smells.

VI. *Burning smells.*—(*a*) Toast, tobacco smoke, creosol, etc. (*b*) Benzol, phenol, etc.

VII. *Caprylic smells.*—(*a*) Caproic acid, cheese, sweat. (*b*) Cat's urine, sexual odours.

VIII. *Repulsive smells.*—(*a*) Narcotic smells. (*b*) The smell of bugs, ozæna.

IX. *Nauseating smells.*—(*a*) Putrefying bodies. (*b*) Fæces, scatol.

Anosmia.—An unsatisfactory attempt has been made to allot to the substances in these different classes certain "odoriferous" atom groups, to which their smell may hypothetically be ascribed. But the system of classification receives some limited support from observations on the order of recovery of sensibility for various odours, after a total loss of smell (general anosmia) has been temporarily produced by artificial means. It is said that the odour of bodies belonging to class VI. returns first; then follows recovery of sensibility towards bodies belonging to class VII. Classes V. and IX. return next, then classes I., II., and III., and lastly classes IV. and VIII.

The hallucinations and the defects of smell, when more carefully studied, may be expected to throw further light on the primary olfactory sensations. Many people are unable to smell prussic acid. Cases are on record of individuals who, while possessing in other respects normal olfactory sensations, are more or less completely incapable of smelling one or other of the following odours :—mignonette, vanilla, violets, frisia, or benzoin. In the study of defects of smell, it must not be forgotten that many stimuli (*e.g.* ammonia) excite not only the special olfactory epithelium, but also the general respiratory epithelium of the nose, giving rise to tactile, pricking, tingling, or painful sensations (exp. 81). We have already noted (page 110) that certain olfactory stimuli also yield sensations of taste.

Fatigue.—The olfactory epithelium is easily fatigued. Yet the effects of exhaustion produced by a single odour do not affect the sensitivity of the nose to all kinds of odours (exp. 82). Here again experiment appears to point to a differentiation of function of the sensory apparatus, certain odours acting on certain end organs, other odours acting on others.

The same conclusion is indicated by the gradual changes in character which many odours undergo while they are being continuously smelled (exp. 83).

Compensation and Rivalry.—The use of perfumes in disguising objectionable smells shows that one odour can be concealed by another. This is quite independent of any chemical interaction between such antagonistic odours. Under favourable conditions, the two odours may be so adjusted that a state of complete, or nearly complete, compensation is reached. A more careful analysis of this phenomenon of compensation may be expected to lead to an improved classification of olfactory sensations. How far the phenomenon depends on central, how far on peripheral factors, is at present unknown; but it is noteworthy that compensation between certain odours may be obtained when they are introduced to separate nostrils.

Zwaardemaker suggests that nine systems of apparatus exist corresponding to his nine classes of olfactory sensations, and that they are ranged in spatial order, those groups of apparatus stimulated by the food smells being placed most anteriorly, those which are stimulated by the nauseating smells being placed most posteriorly, while the sexual odours are represented midway. He believes that, if two odours belonging to neighbouring classes are simultaneously presented to the nose, a new sensation results, apparently simple, but really derived from the elementary constituents; whilst, when the odours simultaneously presented belong to more distant classes, compensation results if the intensity of the odours be weak, and rivalry of the two odours results if they be strong (exp. 84). There are, however, many difficulties in the way of accepting these views.

BIBLIOGRAPHY.

E. Aronsohn, "Zur Physiologie des Geruchs," *Arch. f.* [*Anat. u.*] *Physiol.*, 1884, 163; "Experimentelle Untersuchungen zur Physiol. d. Geruchs," *ibid.*, 1886, 321. J. B. Haycraft, "The Nature of the Objective Cause of Sensation," *Brain*, 1887, x. 145; 1888, xi. 166. H. Oehrwall, "Untersuchungen über d. Geschmacksinn, *Skand. Arch. f. Physiol.*, 1891, ii. 1. L. E. Shore, "A Contribution to our Knowledge of Taste Sensation," *Journ. of Physiol.*, 1892, xiii. 191. F. Kiesow, "Über d. Wirkung d. Cocain u. d. Gymnemasäure auf d. Schleimhaut d. Zunge di. d. Mundraums," *Philosoph. Stud.*, 1894, ix. 510; "Beiträge zur physiol. Psychol. d. Geschmacksinnes," *ibid.*, 1894, x. 329, 523; 1896, xii. 255, 464. H. Zwaardemaker, *Die Physiologie des Geruchs*, 1895; "Die Compensation von Geruchsempfindungen," *Arch. f.* [*Anat. u.*] *Physiol.*, 1900, 423; "Geschmack," in Asher and Spiro's *Ergebnisse d. Physiol.*, Wiesbaden, 1903, Abt. 2, ii. 699. W. Nagel, "Uber Mischgerüche u. d. Komponentengliederung d. Geruchsinnes," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1897, xv. 82; "Der Geruchsinn," in Nagel's *Handbuch d. Physiol. d. Menschen*, Braunschweig, 1905, iii. 589; "Der Geschmackssinn," *ibid.*, 621. A. Rollett, "Beiträge zur Physiol. d. Geruchs, d. Geschmacks, u.s.w.," *Arch. f. d. ges. Physiol.*, 1899, lxxiv. 383. G. Marchand, *Le goût*, Paris, 1903. W. Sternberg, "Zur Physiol. d. süssen Geschmacks," *Ztschr. f. Psychol. u. Physiol. d. Sinnesorgane*, 1904, xxxv. 81; *Geschmack u. Geruch*, Berlin, 1906. C. S. Myers, "The Taste-names of Primitive Peoples," *Brit. Journ. of Psychol.*, 1904, i. 117.

CHAPTER IX

ON THE SPECIFIC ENERGY OF SENSATIONS

Adequate and Inadequate Stimuli.—The "adequate" stimulus to any sense organ is the special kind of stimulus to which the sense organ is adapted to respond. Light, for instance, is the adequate stimulus in the case of the retina, sound in the case of the cochlea. Other kinds of stimuli to which a sense organ may respond, are spoken of as "inadequate" stimuli.

There is good reason to believe that every sense organ, whether it be excited by an adequate or inadequate stimulus, gives rise only to its own specific sensation. Most observers agree that a cold spot on the skin may be excited by cold, by pressure, by warmth, or by a faradic current; but in each case a sensation only of cold is evoked (exp. 3). So, too, an electric stimulus produces a sensation of pain, heat, cold, or pressure, according as it is applied to a pain, a heat, a cold, or a touch spot; a blow on the eye produces visual, a blow on the ear auditory, sensations.

Effective and Ineffective Stimuli.—On the other hand, sense organs do not respond to every form of inadequate stimulus. The ear, for example, is not stimulated by waves of light, nor the eye by waves of sound. Stimuli may thus be classed as effective and ineffective. Electrical and mechanical (*e.g.* blows or pressure) are the most generally effective of all stimuli.

The effectiveness of electrical stimuli is often partly due to the adventitious production of adequate stimuli. Thus

the auditory sensations, arising from the application of a current to the ear, are in part the result of sounds occasioned by the contracting muscles of the middle ear. And the gustatory sensations, electrically evoked from the tongue, are in part due to the tasting substances which are produced by the electrolytic decomposition of salivary and mucous secretion. But altogether aside from such secondary effects, electrical stimuli seem to be universally and directly effective as inadequate stimuli.

Specific Nervous Energy. — Johannes Müller supposed that every sensory nerve or every sensory nerve centre possesses its own "specific nervous energy" which gives rise, in the case of the eye, for example, to visual, in the case of the ear to auditory sensations. Müller's theory was that any stimulus, so long as it is effective, invariably evokes the same specific energy in a given sensory apparatus. He allowed, however, that any sensory apparatus may respond in a variety of ways to different forms of adequate stimuli. This admission serves to explain the various colour sensations producible in the retinal apparatus, and similar phenomena in other sense organs.

It is true that we have no anatomical or physiological evidence in favour of the existence of specific nervous energies in different sensory nerves or in different sensory centres. So far as we know, the nervous impulses passing to the brain along a gustatory nerve do not differ in any way from those passing, say, along an auditory nerve. Nor is it clear how the cortical centres for taste and for hearing can owe their differentiation of function to differences in their structure, connections, or chemical composition. On the other hand, if we cling to the hypothesis of psycho-physical—or rather of psycho-physiological (page 9)—parallelism, we cannot but believe that ultimately a satisfactory physiological basis will be found for these differences in sensation, produced by the stimulation of different kinds of end apparatus.

The importance of the peripheral sense organs in initiating the various specific forms of sensation can hardly be overrated. If the end organs have been congenitally useless and remain so, no experience to which they would normally give rise is ever possible. Individuals who are born blind (or indeed who lose their eyesight within the first few years of infancy) have no visual sensations and no visual images when awake or when dreaming in later life.

But when once the corresponding cortical centres have been educated, their specific activity may be subsequently evoked by stimulation either of the centres themselves or of their appropriate sensory nerves. Stimulation of the chorda tympani nerve in the ear gives rise to sensations of taste: stimulation of the optic nerve after excision of the eye,—in certain circumstances at least,—produces a sensation of light. Even when the sensory nerve is completely degenerated, as in atrophy of the optic nerve, the cortical centres may still be excited, and hallucinations of vision may occur.

Quality and Modality. — The result of an appeal to experience is to establish two kinds of differences between sensations, — differences of "quality" and differences of "modality." Two sensations are said to be qualitatively different from one another, when it is possible to pass insensibly from the one to the other by means of a series of insensibly changing intervening sensations. They are said to be modally different when such a transition is impossible.

Thus, any two visual sensations differ in quality as regards colour or colourlessness, inasmuch as we can pass from any one sensation to the other by gradual imperceptible changes. A gustatory sensation, on the other hand, differs from a visual sensation in modality; no gradual transition is possible between the sensations of sweetness and greyness. So, too, we cannot pass from an olfactory to an auditory sensation, or from a motor to a thermal sensation. Such sensations differ in modality.

Primary Sensations.—We can hardly, however, be content to ascribe specificity of energy to modally different sensations and to deny it to qualitatively different sensations. We have already travelled far beyond Müller's hypothesis in which a single specific nervous energy is provided for each sense organ; we have sought for various specific nervous energies within the individual sense organs.

In the case of vision, we have collected evidence which indicates that the numerous, introspectively distinct, colour and colourless sensations are the functional result of a relatively very small number of specific or "primary" sensations. The same result is indicated in the case of olfactory gustatory and cutaneous sensations.

It is impossible at present to determine the number of primary sensations in respect of hearing. Many writers have assumed that there are as many distinct end organs in the cochlea as there are distinguishable sensations of tone, but this assumption is demonstrably wrong. For let us suppose that the ear is just able to distinguish between an auditory stimulus of 999·5 vibrations and one of 1000, and between a stimulus of 1000 and one of 1000·5 vibrations per second. It has been said that this implies that a specific end organ exists for each of these three stimuli, and that the reason why we cannot distinguish between, say, 999·8 and 1000 vibrations is because they both act on the same end organ. For a like reason stimuli of 1000 and 1000·3 vibrations per second are indistinguishable. But were this the true explanation, it would at once follow that the two stimuli of 999·8 and 1000·3 vibrations should be indistinguishable, whereas in fact they can be distinguished from one another as easily as stimuli of 1000 and 1000·5 vibrations. We conclude, then, that the number of just distinguishable sensations affords no clue to the number of primary sensations or of specifically different end organs.

Moreover, even if there be grounds for believing that within a given sense organ a few primary sensations,

variously combined, are responsible for all the sensations to which it gives rise, we are nevertheless not warranted in concluding forthwith that that sense organ contains corresponding, structurally distinct, end organs. In the case of the cerebro-retinal apparatus, for example, no satisfactory evidence has been adduced in favour of attributing different specific colour functions to different cones of the fovea, to different optic fibres, or to different parts of the visual cortex.

In such cases, two alternative assumptions are possible. In the first place, we may assume that one and the same "specific energy" (to use Müller's terminology) may manifest itself in two, three or more abruptly or gradually different ways. This may be the case in vision and in taste. It was also generally thought to occur in pain, many writers still holding that pain may arise from the overstimulation of any sensory end organ.

In the second place, it is conceivable that the primary sensations lie beyond our ken, for the very reason that they are never separately experienced. If from birth onwards, our simplest obtainable sensations arise from the excitation of more than a single primitive sensory apparatus, it is clear that no normal individual can ever obtain the experience which the isolated activity of such a primitive apparatus produces.

From two different aspects this latter conception may be said to hold for tonal sensations. In the first place, we have already pointed out (pages 57, 58) that the cochlea probably never receives a pure tonal stimulus which is absolutely devoid of overtones. It is thus impossible for us ever to have the pure tonal sensation, which, according to Helmholtz's theory, would arise from the stimulation of a given basilar fibre in the cochlea. In the second place, we have also shown reasons (pages 52, 53) for believing that, if Helmholtz's theory is to be accepted, the pitch of a sensation must depend not merely on the particular basilar fibre

stimulated, but on the position of the most intensely stimulated basilar fibre. Thus we can never experience the result of stimulating a single basilar fibre, and our tonal sensations are the result of a fusion between various primordial elements of which we must always remain ignorant. A somewhat similar condition is conceivably true of olfactory sensations.

The fusions which we can experimentally bring about, by simultaneously presenting different sensory stimuli, show how different are the psycho-physiological factors which determine our experiences in the different senses. It is sufficient to mention the very different kinds and degrees of fusion obtained by mixing two or more similar or antagonistic colour or colourless stimuli, by mixing two or more tones of similar and of dissimilar pitch, or by mixing gustatory or olfactory solutions.

BIBLIOGRAPHY.

J. Müller, *Elements of Physiology* (Eng. trans.), London, 1842, ii. 1059. R. H. Lotze, *Medicinische Psychologie*, Leipzig, 1852, 182. H. L. F. von Helmholtz, *Die Thatsachen in d. Wahrnehmung*, Berlin, 1879, 8; *Handbuch d. Physiol. Optik*, 2te Aufl., 1894, 584. E. Hering, "Ueber d. specifischen Energieen d. Nervensystems," *Lotos*, 1884 (N.F.), v. 113. C. Stumpf, *Tonpsychologie*, Leipzig, 1890, ii. 106. H. Oehrwall, "Untersuch. über d. Geschmacksinn," *Skand. Arch. f. Physiol.*, 1891, ii. 1; "Ueber d. Modalitäts- u. Qualitätsbegriffe in d. Sinnesphysiol." *ibid.*, 1901, xi. 245. F. Kiesow, "Schmeckversuche an einzelnen Papillen," *Philosoph. Stud.*, 1898, xiv. 591. A. Goldscheider, "Die Lehre von d. specifischen Energieen," *Gesammelte Abhandlungen*, Leipzig, 1898, i. 1. W. Wundt, *Grundzüge d. physiol. Psychol.*, Leipzig, 5te Aufl., 1902–3, i. 330, 337; ii. 15, 52, 123, 132; iii. 711.

CHAPTER X

ON STATISTICAL METHODS[1]

Their Importance.—It is incompatible with scientific method to draw conclusions from the result of a single observation. The reliability of a single observation must be tested by several repetitions of the experiment under conditions as precisely constant as possible. In such a series of repeated experiments we can rarely obtain identical results. Where the results appear to be identical, more refined methods of measurement will surely show minute differences.

This discrepancy between individual results, due to the variation of uncontrollable circumstances, increases with the complexity of the conditions of experiment. In psychology it is only natural that stricter attention should be paid to such discrepancies than in other branches of science, for nowhere are the experimental conditions so complicated as in the investigation of mental phenomena.

Indeed, it is important at the outset to recognise that average results are of relatively small value in psychology. Whereas physical science treats errors of observation as accidental, and endeavours, so far as possible, to eliminate them, in psychological science the causation of these errors is the prime object of investigation. From the psychological standpoint an average is often a blurred result, the chief value of which is to draw attention to the individual variations, and to the conditions producing them.

[1] See footnote to Chapter III.

The Mode.—The "mode" is the value of that measurement which occurs more frequently than any other in a large series of observations.

The Mean.—The "mean" or "average"[1] is obtained by dividing the sum of the values by the number of the individual observations. The reliability of the mean depends, in the first place, on the number of the observations which have been made, and, in the second place, on the variability of the individual values, that is, on the extent to which they each diverge from the mean. No reliance can be placed on a published mean unless it is accompanied by information on these two points. The variability of the individual values may be best expressed either by the "mean variation" or by the "standard deviation."

The Mean Variation.—The "mean variation," or the "mean variable error," commonly denoted by the letters *m. v.*, is the mean of the individual variations from the mean, regardless of algebraic sign (exp. 85).

The Standard Deviation.—The "standard deviation" or the "mean square error,"[2] denoted by the letter σ, is the square root of the mean of the squares of the individual variations from the mean (exp. 85).

[*The Coefficient of Variation.*—The deviations of individual data from their mean depend for their absolute size, not only on the uniformity of the experimental conditions, but on the absolute size of the mean. Thus a mean of 200 which has a standard deviation of 20 need not be less reliable than a mean of 100 which has a standard deviation of 10. Accordingly, a measure of *relative* dispersion is sometimes employed, the standard deviation being expressed as a percentage of the mean. This measure has been termed the "coefficient of variation" (exp. 85).]

[1] These terms are used throughout this book to refer to the *arithmetic* mean, but sometimes they are given a wider signification.

[2] "*Root* mean square error" is a more accurate, though more cumbrous, expression.

[*Significant Differences.*—It is obvious that the mean of so small a series of observations as that with which we have to content ourselves in any scientific experiment, is only an approximation to the value obtained from a larger series. Different values of the mean would result from successive series of observations. In other words, the mean, experimentally obtained, is only the mean of a single sample of observations, different samples of which are certain to give somewhat different means. This fact becomes of enormous importance, when one set of experimental conditions produces a mean result, which differs from that obtained under a purposely different set of experimental conditions. The question then arises, Is this difference between the means significant or is it accidental,—that is to say, does it really express the effect of the intentionally altered experimental conditions, or may it not after all be due to the chances of sampling above referred to ?

To settle this question, we have to consider the probable distribution of such chance variations of the mean, say, in a thousand samples of observations, each sample consisting of, say, two hundred measurements, and obtained under conditions as constant as possible. Clearly, the values of the thousand different means will range about a single mean of the possible means. The greater number of values will occur at or near this point, and others will occur in diminishing number as we recede from it. If we assume (and in the absence of other information we have no alternative than to assume) that the single, experimentally obtained, mean is identical with the value of the mean of the thousand possible means, we are able to study the mode of distribution of the other means on either side of it, by having recourse to the properties of the "normal" or "probability" distribution curve of Gauss's law of error.]

[*The Normal Curve.* — In order to understand this application of the normal curve, let us suppose that a con-

siderable number of measurements be made of a complex variable character, *e.g.* by determining the successive results of throwing heaps of coins or by determining the stature of unselected individuals within a given community. If now such a series of observations (or "variates," as they are often called) be plotted out in a frequency curve—the distances along the abscissa corresponding to the different values of the character, the height of the ordinates erected at these distances corresponding to the number of individual variates that have the corresponding character,—the curve will be found to approximate in form to that of the normal or probability curve (fig. 3), which has well-known mathematical properties.

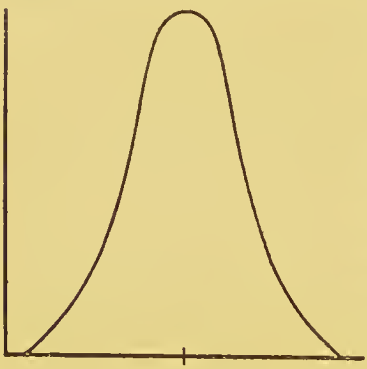

Fig. 3.

This normal curve is sometimes called the binomial curve, because the values of the ordinates follow the coefficients of the binomial expansion of an expression $(x+y)^m$, in which the two terms are equal to one another. Thus, if $m=10$, the following ordinates will mark the course of the curve:—

$$10, \left(\frac{10 \times 9}{2} = \right) 45, \left(\frac{10 \times 9 \times 8}{1 . 2 . 3} = \right) 120, 210, \ldots\ldots 210, 120, 45, 10.$$

That is to say, the ordinates, erected at certain equidistant points of the abscissa to meet the curve, will have those values.

The mode is at the point A, on the abscissa, at which the maximal ordinate occurs.

The standard deviation marks the point on the abscissa at the point of inflexion of the normal curve, *i.e.* where the form of the latter changes from concave to convex.

A knowledge of the mathematical properties of the normal curve enables us to calculate the value of the

ordinate (*i.e.* the frequency of occurrence) at any point on the abscissa (*i.e.* in the case of any magnitude of character), provided that the values of A, the mean, σ, the standard deviation, and n, the number of variates, are known.

While σ, the standard deviation, expresses, as we have already seen, the degree of scatter of individual variates about the mean, $\frac{\sigma}{\sqrt{n}}$ gives the standard deviation or scatter of the numerous values of the mean derived from many, say a thousand, samples like the present one. The distribution curve of the possible means, like that of the individual variates within the present sample, conforms to the normal frequency curve.]

[*The Probable Error.*—It can be shown that 50 per cent. of these various possible means lie within the limiting values which are greater or less than the mean of those means by $\frac{0{\cdot}6745\sigma}{\sqrt{n}}$. This expression $\pm\frac{0{\cdot}6745\sigma}{\sqrt{n}}$ is known as the probable error, E, of the mean. That is to say, there are even chances that a mean obtained from any other sample will lie within the limits A ± E. It can also be shown that the chances of any value of the mean lying

within the limits of	A ± 2 E	are about	4·6 : 1
" "	A ± 3 E	"	16 : 1
" "	A ± 4 E	"	142 : 1
" "	A ± 5 E	"	1341 : 1
" "	A ± 6 E	"	19304 : 1
" "	A ± 7 E	"	426910 : 1

The chances against any found value of the mean lying within the limits $A \pm \frac{E}{2}$, $A \pm \frac{E}{3}$, etc., can be also calculated.

Thus we have reached a stage in which we have know-

ledge of the distribution (i.) of the individual variates of a sample series, and (ii.) of the individual means of different sample series.

We can now return to our original question which presupposed that, under expressly altered experimental conditions, we have obtained two different series, each with a different mean. We required to know when the difference between two means may be regarded as significant, and when it is more likely to be due to chance sampling.

If A_1 and A_2 be the means of the two series, it is clear that the distribution of the different values of these means in different sample series can be determined, when their probable errors E_{A_1} and E_{A_2} have been calculated. But we have now to consider the distribution of different values of the possible differences between these different values of A_1 and A_2. The probable error of the difference of two means can be shown to be equal to the square root of the sum of the squared probable errors of these means, that is, $E_{A_1-A_2} = \sqrt{(E^2_{A_1} + E^2_{A_2})}$.

When the difference between two means turns out to be only equal to the probable error of the difference between them, *i.e.* when $A_1 - A_2 = E_{A_1-A_2}$, the chances are only about three to one against an equal or greater difference of the same sign occurring in a case of pure sampling. In order that an observed difference between two means can be safely accepted as significant, it must at least exceed four and a half times the value of the probable error of the difference (exp. 86). Thus we have at length answered the question which confronted us on page 125.]

The Median.—Besides the mean and the mode, a third expression, the "median" (Mdn.), is sometimes employed in order to generalise from the individual data of a given series. The variates are arranged in their order of magnitude, and the median is that value above and below which the variates occur in equal numbers (exp. 85).

[If the distribution of the variates obeys that of the

probability curve,—and for a considerable number of different psychological investigations, provided that the series be large enough, this has been shown to be nearly or absolutely the case,—the median value is identical with the mode and mean. Some distributions, however, follow other forms of curve. In the case of unpractised reaction times, for example, the curve has a highly marked skew instead of a symmetrical shape. For while there is no limit to the possible length of a reaction time, there is an obvious limit to its possible shortness.]

It is particularly when we are dealing with distributions in which a few exceptionally large or small variates are liable to disturb the value of the mean, that the median presents a truer generalisation of the experimental results than can be obtained from the mean. But since in very small series, the median cannot be trusted to give a reliable result, and in sufficiently large series, such chance abnormally large or small values do not so seriously affect the mean, the chief advantage of the median comes to lie in the ease with which it may be determined.

The Semi-interquartile Range.—The median represents the value of the central variate. It is sometimes useful to know the value of other definitely placed variates, *e.g.* the variates which lie half-way between the median and the two extreme variates. Two such variates, in this particular case termed quartiles, are sometimes employed to indicate the extent of variation in the series. For this purpose half the difference between the quartiles is a useful expression. It may be termed the "semi-interquartile range."

Correlation.—In psychological experiment we are often concerned with determining the correlation between the members of two series of measurements. We require to know how far the values of variates in the one series vary concurrently with those in the other,—to what extent, for

example, those individuals who give high or low values in one particular mental trait also give high or low (or low or high) values in another trait.

The mathematical symbol, r, is used to express the coefficient of correlation between two such traits. A very widely useful formula for determining it is

$$r = \frac{\Sigma(xy)}{n\sigma_x\sigma_y}$$

where x and y are the deviations of the two traits from their mean in any single individual, $\Sigma(xy)$ is the sum of these several products of x and y obtained for all the individuals, σ_x and σ_y are the standard deviations of the two series of measurements, and n is the number of individuals (or pairs of measurements) examined. The probable error of this coefficient of correlation is given by the expression

$$\frac{0{\cdot}6745\,(1-r^2)}{\sqrt{n}}.$$

The possible values of r range between $+1$ and -1. When r is found to be zero, the two traits are absolutely devoid of correlation; when $r = 1$, there is perfect correlation; when $r = -1$, there is perfect inverse correlation,—that is to say, every individual who shows high values in one trait shows correspondingly low values in the other trait.

This formula can be considerably simplified when correlation is studied, not, as before, between two series of measurements, but between two series of ranks. The simplification arises from the fact that the variates are now whole numbers from 1 to n, and that their standard deviation can consequently be calculated once and for all. The individuals are arranged in order of rank, first as regards one trait and then as regards the other. Each individual thus receives two numbers which represent his

rank in respect of each trait. Then it can be shown that the previous formula

$$\frac{\Sigma(xy)}{n\sigma_1\sigma_2} = \frac{12\left[\Sigma(xy) - \frac{n(n+1)^2}{4}\right]}{n(n^2-1)} = 1 - \frac{6\Sigma(d^2)}{n(n^2-1)},$$

where $\Sigma(d)$ is the sum of the differences between each of those pairs of numbers. Either of these formulæ is a much more convenient expression to use (exp. 87).

BIBLIOGRAPHY.

K. Pearson, *The Grammar of Science*, London, 1900, 372–503. C. Davenport, *Statistical Methods*, New York, 1904. E. L. Thorndike, *An Introduction to the Theory of Mental and Social Measurements*, New York, 1904. C. Spearman, "'Footrule' for Measuring Correlation," *Brit. Journ. of Psychol.*, 1906, ii. 89 ; "The Method of 'Right and Wrong Cases' ('Constant Stimuli'), without Gauss's Formulæ," *ibid.*, 227.

CHAPTER XI

ON REACTION TIMES

Simple and Composite Reactions.—The reaction time of an individual is the interval that elapses between the exhibition of a stimulus and his response to it in a prescribed manner. The reaction or response is usually carried out by movement of the hand or lips, or by articulation. The quickest reaction is obtainable by an immediate response to a previously known and simple presentation. But, as we shall see, various complexities, as regards the nature of the stimulus and the mode of the reaction, may be introduced; these materially modify the length of the reaction time. It is therefore convenient to distinguish "simple" from "composite" (or complex) reactions.

The Reduced Reaction Time.—The time of the simple reaction (*i.e.* immediate reaction, say, to a sound, a touch, or a taste) is occupied partly in central changes taking place within the brain, and partly in peripheral changes which occur outside it. Endeavours have been made to arrive at a central or "reduced" reaction time, by eliminating the time that is spent peripherally in the action of the stimulus on the sensory organ, in the passage of the afferent and efferent impulses along the peripheral nerves and within the spinal cord to or from the cerebral hemispheres, and lastly in the conversion of the efferent impulse into the muscular contraction which forms the response.

Unfortunately, our knowledge of the speed of these physiological processes is not accurate enough to make such

calculations reliable. Yet they are unquestionably the cause of certain differences in reaction time. Thus the slower reaction to visual stimuli, as compared with the reaction to all other (save painful) sensory stimuli, is largely due to the latent time occupied in the development of photochemical processes in the retina. And the slower reaction to bitter than to other tastes is doubtless of similar causation. But, in our present ignorance, we have for the most part to leave these variable peripheral factors on one side, and to confine our studies of reaction times to a comparison of the results obtained under different psychical conditions from the same individual or from different individuals.

Simple Reactions.

Sensorial and Muscular Reactions.—Simple reaction times vary in length, according to the direction of the reagent's attention at the moment of exhibition of the stimulus. If he attend to the movement by which he is enjoined to respond, he generally reacts with considerably greater speed than if his attention be fixed upon the stimulus which he is about to receive. The approximate differences between the "muscular" and the "sensorial" reactions, as these two modes of reaction are called, are here given:—

Stimulus.	Muscular Reaction.	Sensorial Reaction.
Sound . . .	125^σ	220^σ
Light . . .	175^σ	270^σ
Touch . . .	110^σ	210^σ
Heat . . .	130^σ	190^σ
Cold . . .	115^σ	150^σ

These figures express the reaction times in one thousandth

parts of a second, a unit for which the symbol σ is usually employed.[1]

There are other particulars in which muscular reactions differ from sensorial. As a rule, they show considerably less variability. Thus, while the mean variation (page 124) of the former lies between 6^σ and 9^σ, the mean variation of the latter after a corresponding degree of practice is from 24^σ to 28^σ. Further, whereas "premature" and "wrong" or "delayed" reactions are liable to occur in muscular, they are absent in strictly sensorial reactions. A subject is said to react "prematurely," when he inadvertently reacts before the stimulus is given or before it can have been received by him. He reacts "wrongly," when he responds to some accidentally occurring stimulus other than that prescribed. His reaction is "delayed," when he responds to the prescribed stimulus after having tended to give, or after having actually given, a "wrong" reaction (exp. 89).

These several features of the muscular and sensorial reaction are precisely those we should expect to result from the differences in mental attitude of the reagent. In the muscular reaction, his attention is confined to the response which is expected of him. Whether the reaction consists in the lifting of a finger or in the speaking of a word, the reagent has prepared the appropriate motor apparatus for action before the arrival of the stimulus. So delicately is his system balanced, in such readiness does he hold himself, that he tends, as we have seen, to "go off" (wrongly or prematurely) into movement on the least provocation; the vivid idea of movement uncontrollably expresses itself in action. In the sensorial reaction, on the other hand, the subject's attention is occupied, not with the response, but with an idea of the impression which he is about to receive. Upon receiving the impression, he has first to assure himself that it is truly the expected presentation, whereupon he

[1] It is unfortunate that this time interval and the standard deviation are denoted by the same symbol. In practice, however, no confusion results.

reacts in the prescribed manner. It is not surprising, then, that sensorial are slower than muscular reactions.

Psychological Analysis of Reaction Times.—The central or reduced reaction time (page 132) may be conceived as spent in three different mental processes, namely, the perception of the impression, its apperception, and the volitional release of the motor response. This conception, however, is schematic instead of actual: philosophical instead of psychological. It is the outcome of *a priori* notions, rather than of an appeal to introspection.

For even in the sensorial reaction the distinction between perception and apperception of the impression,—that is, between vague awareness and attentive notice of it,—is ill-defined, while in the practised muscular reaction introspection fails to reveal any trace of apperception prior to the response. And as regards the third of these processes, the release of the motor response, we have to bear in mind that in either form of reaction it is very far from being identical with an ordinary act of volition. In the sensorial reaction the subject has already decided how he will react, before he receives the appropriate impression. In the muscular reaction the practised subject finally responds automatically. Here there is no conation; nor is there the faintest kinæsthetic image of the intended movement. His reaction becomes, to all intents, a reflex,—a reflex which is sustained so long as he volitionally preserves a psychologically favourable disposition toward the experiment. Under such conditions, we are merely measuring the speed with which an already established sensori-motor connection finds expression.

Effects of Practice and Fatigue.—The improvement in the speed of reaction, effected by practice, is the result of a more perfect adaptation to the conditions of experiment. As we might expect, it is more noticeable in sensorial than in muscular reactions; indeed, ultimately, the difference in their times may be considerably less than that given in the

previous table. At the outset of any series of experiments, the reagent is naturally far worse prepared in the sensorial than in the muscular reaction. Practice teaches him how to combine a certain readiness for movement with the fixation of his attention on the expected stimulus, and thus the practised sensorial approaches more and more nearly to the value of the muscular reaction time.

The effects of fatigue upon the reaction time are relatively slight. They are chiefly due to the failure of attention.

Reaction Movements.—A careful study of the variations in finger pressure, which different reagents bring to bear upon the reaction key during reaction experiments, shows individual differences of behaviour, of the significance and effect of which we are at present ignorant. Some reagents habitually maintain a constant pressure on the key while awaiting the expected signal; some rhythmically increase and decrease this pressure; some gradually or suddenly decrease the pressure before the reaction; while others gradually or suddenly increase it before the reaction, giving what has been termed an "antagonistic" reaction.

Natural Reactions.—A third form of simple reaction has yet to be mentioned, in which the subject's attention is left altogether undirected. He is merely enjoined to react when the stimulus has been exhibited. This is called the "natural" reaction; its time is commonly intermediate between the values of the sensorial and muscular reaction times, the mental attitude now tending toward a sensorial, now toward a muscular reaction (exp. 89).

Individual Variations.—But individual variations are considerable. Some reagents when left to themselves are naturally prone to react exclusively in the muscular or exclusively in the sensorial fashion. Even after considerable practice some find it difficult, or indeed impossible, to change the mode of their reaction from one form to the other. It has been said that some reagents give quicker sensorial than muscular reactions.

Apparently it is easier for the natural reaction of those who incline to the sensorial to be changed to the muscular form after continued practice at the latter, than for the natural reaction of those who incline to the muscular to be changed to the sensorial form after practice at sensorial reactions.

Attempts have been made to correlate these individual differences in reaction with individual differences in imagery. A person in whom motor imagery predominates would incline, so it has been said, to the muscular reaction, while a difficulty in reacting sensorially would result from his inability to preserve that clear image of the expected stimulus, which persons endowed with vivid auditory, visual or other imagery, could attain. Although the evidence in favour of such a connection between type of reaction and of imagery is somewhat conflicting, it may reasonably be supposed that in a slight degree they are correlated.

Influence of Age and Race.—In childhood and in old age, natural reaction times are longer and their mean variations are larger than in intervening periods of life, a result which is doubtless to be attributed to a more difficult maintenance of the favourable attitude of readiness, owing to wandering attention, lack of agility, and the like. The racial differences that exist in reaction times are largely the outcome of similar psychological factors, determined by habits of life and possibly by some obscure racial tendency to react rather in the sensorial than in the muscular fashion, or *vice versâ*.

The Personal Equation. — Observations on individual differences of reaction time throw light on the nature of the so-called "personal equation," which astronomers have long recognised and taken into account, in the comparison of transit observations made by different observers. If to the individual differences in reaction time we add the alterations of apparent time order, produced by change of the field of attention (page 317), we can fairly picture the

psychological causes of those errors to which the astronomer is liable, when he registers the moments at which a moving star crosses the parallel lines fixed within his telescope, either by registering those moments or by counting the beats of a clock.

Other Determinants of Reaction Times.—We have already pointed out (page 132) that the reaction time must partly depend upon the time occupied at the peripheral sense organ in developing the afferent nervous impulse. Moreover, it is conceivable that all sensations do not travel by equally direct or easy paths from the periphery to the centre. This may perhaps help to explain the longer latent period in the development of sensations of pain, compared with those of touch.

The reaction time varies in the case of different sensations of the same sense organs. It is generally shorter for high than for low tones, and shorter for noises than for tones. Such variations are probably due less to peripheral physiological factors than to factors of a more complex "psychological" order.

The strain on the attention, produced by the use of extremely feeble stimuli, leads to prolongation of the reaction time. Very faint presentations, whatever be their nature, have been said to yield a uniform reaction time of about 330^{σ}. As might be expected, reaction times are lengthened and their mean variation is increased, when the stimuli vary irregularly from reaction to reaction in intensity or quality, or when the reagent never knows when he may expect the stimulus. The quickest reactions are obtained, when a warning signal precedes the exhibition of the stimulus by an interval of between one and two seconds.

Composite Reactions.

Recognitive and Discriminative Reactions.—There are various means by which the apperceptive and volitional

factors, vaguely shadowed in the simple sensorial reaction, may be brought still more to the fore. The reagent may be instructed not to react until he has "recognised" in full detail the presentation. Or a variety of stimuli, with which the reagent is already more or less familiar, may be used, and he may be enjoined to "discriminate" between the particular stimulus presented and the other possible stimuli before he reacts. By these means, the reaction time is prolonged by a period varying from 30^σ to upwards of 100^σ, according to the difficulty of the mental process involved (exp. 90).

Choice Reactions.—The complexity of the experiment may be further increased by employing two stimuli and by enjoining the subject (i.) to react if the one stimulus appears and not to react for the other, or (ii.) to react in one way (*e.g.* lifting one finger or one hand) for the one stimulus and to react in another way (*e.g.* lifting another finger or the other hand) for the other stimulus. The subject has here not only to recognise and to discriminate between the individual presentations, but to behave differently towards each of them.

Such "choice" reactions are longer by about 70^σ than the corresponding "discriminative" reactions. The reaction becomes still further delayed, the greater the number of possible stimuli and of modes of reaction introduced. When they are ten in number, when, for example, a different finger of one or other hand must react for each of ten different possible presentations, the average choice reaction time has been found to exceed the discriminative reaction time by about 400^σ (exp. 90).

Naming and Reading Reactions.—Instead of reacting by finger movement, the reagent may be required to name or to read the presented stimulus; in such experiments the act of articulation becomes the reaction movement. It appears that while the time, occupied in the reading of short words (about 390^σ), is not sensibly different from the

choice reaction time for two words, the time occupied in naming colours (about 550^σ) is distinctly longer than the choice reaction time between two colours (about 350^σ).

All these forms of composite reactions are far more readily executed by the subject who naturally tends to the sensorial variety of simple reaction. The individual, who would react muscularly, must needs learn to control his reaction movement until the presentation has been recognised or discriminated, or until the appropriate movement has been decided upon.

Psychological Analysis of Composite Reactions.—We have already pointed out (page 135) how the volitional element in the simple reaction differs from a volitional act in the ordinary sense of the term. So, too, the processes of recognition, discrimination, and choice in composite reactions are very far from being comparable with those processes in ordinary life. To some extent the reagent is already familiar with the demands about to be made on him, before any individual reaction is carried out. If, for example, he be required to discriminate between two colours or between two sounds, he will have already seen or heard these stimuli in previous reactions. Or again, if he have to choose between various modes of reaction, there very soon ceases to be a genuine deliberate choice between the ideas of possible movements which occur to him when the stimulus is presented. After a little experience he immediately recognises the idea corresponding to the correct movement, just as he would directly and without the intervention of choice identify the correctness of the revived image of a word which he had previously learned in association with another word. Thus choice reaction times give place to what in memory we call reproduction times (page 154). Finally, with sufficient practice the reagent plays upon the reaction keys as automatically as an accomplished pianist comes to read a piece of music set before him at the piano-

forte, each impression unconsciously releasing the appropriate movement.

Associative Reactions.

In point of fact, all reactions involve various processes of association, but the "associative reaction" is a term given to the experiment in which the reagent has to respond to the word stimulus by another word (or idea) which is somehow associated with it (exp. 91).

Forms of Associative Reactions.—The association may be "free" or "wholly" or "partly constrained." It is free, when the subject replies to the stimulus (a word heard or read) by giving the first idea that occurs to him. It is wholly constrained, when practically only one correct response can be returned by him; thus he may be asked to translate a foreign word presented to him, to perform a mathematical calculation, or to name the capital of a given country. The association is partly constrained, when, for instance, a generic word is exhibited and the subject is required to reply with a specific example, or when an adjective is exhibited and the reagent is required to name a noun to which the epithet is appropriate.

Association Times.—Associative reactions are on the average about 700^σ longer than reactions in which the presented word has merely to be articulated. But there are wide variations in the times of individual associative reactions. They may range from 700^σ to over 1400^σ, according to the nature of the association and the mental condition of the reagent; they are generally longer in free than in constrained associations. In a later chapter we shall deal with the classification of associations, and we shall show how the times of wholly constrained associations (in other words, how reproduction times) may be used as a test of the strength of associations.

Mathematical Analysis of Reaction Times.—Certain psy-

chologists have not hesitated to subtract the times of these various forms of reaction from one another, thinking thereby to arrive at the speed of the special mental processes involved in the different reactions. Thus, they have believed it possible to determine the time taken up in recognition by subtracting the mean simple reaction time from the mean recognitive reaction time, and to determine the time taken up in choice by subtracting the mean discriminative reaction time from the mean choice reaction time, and so on. But such mathematical treatment of psychological data is utterly indefensible, unless it be grounded on most careful introspection. We must recognise that the formal schemes of abstract thought, dictated by logic or by mathematics, are not necessarily followed in the concrete. And even when separate procedures of the mind may be introspectively separated from a complex piece of mental behaviour, it by no means follows that, when a third psychical process is experimentally added to two others, these latter preserve their nature and duration, undisturbed by the entry of the third. On the contrary, there is *a priori* every reason to suppose that they will be modified.

The Physiological Aspect of Reaction Times.—We have to guard against the common inference that as any piece of behaviour becomes more purely reflex, the nervous paths traversed must necessarily become more and more confined to the lower parts of the brain and to the spinal cord. There is no evidence to show that an acquired habit ever quits the motor cortical paths which from the outset it had taken. Were it the case, were the acts handed over from cortical to subcortical and finally to spinal areas as they become more habitual, we might expect the effects of continued practice with which we meet to be interrupted instead of gradual. And we should expect that where, through injury or disease, the cortical motor centres are put out of action and the lower nuclear centres remain in function, habitual acts would still be capable of performance;

but this is not found to be the case. On the contrary, the evidence is strongly in favour of the view that the conscious or unconscious performance of an action is, on the whole, correlated with the degree of difficulty of its performance, and that both the degree of consciousness and the difficulty of performance are, in part at least, the expression of the resistance which is offered at the centres to the passage of the nervous impulses, and which becomes reduced by adequate practice.

BIBLIOGRAPHY.

G. Buccola, *La Legge del Tempo nei Fenomeni del Pensiero*, Milano, 1883. L. Lange, "Neue Experimente über d. Vorgang d. einfachen Reaction auf Sinneseindrücke," *Philosoph. Stud.*, 1888, iv. 479. L. W. Stern, *Ueber d. Psychol. d. individuellen Differenzen*, Leipzig, 1900, 103. N. Alechsieff, "Ueber Reaktionsversuche bei Durchgangsbeobachtungen," *Philosoph. Stud.*, xvi. 1900, 15. C. S. Myers, *Reports of the Cambridge Anthropol. Expedition to Torres Straits*, Cambridge, 1903, ii. 205. W. G. Smith, "Antagonistic Reactions," *Mind*, 1903 (N.S.), xii. 47. W. Wundt, *Grundzüge d. physiol. Psychol.*, Leipzig, 5te Aufl., 1903, iii. 315. C. H. Judd, C. N. M'Allister, and W. M. Steele, "Analysis of Reaction Movements," *Psychol. Rev.*, Monograph Suppl., 1905, vii. No. 1, 141. E. B. Titchener, *Experimental Psychol.*, New York, 1905, i. exp. xxvi.; ii. chap. 3. A. Aliotta, *La Misura in Psicologia sperimentale*, Firenze, 1905. R. Bergmann, "Reaktionen auf Schalleindrücke, nach d. Methode d. Häufigkeitskurven bearbeitet," *Psychol. Stud.*, 1905, i. 179. H. J. Watt, "Experimentelle Beitr. zu einer Theorie d. Denkens," *Arch. f. d. ges. Psychol.*, 1905, iv. 289. B. Edgell and W. L. Symes, "The Wheatstone-Hipp Chronoscope," etc., *Brit. Journ. of Psychol.*, 1906-8, ii. 58, 281.

CHAPTER XII

ON MEMORY[1]

The Perseverance of Experiences.—The tendency of past experiences to reproduce themselves spontaneously constitutes their tendency to "perseverance." The "running" of a tune in the head, the persistent revival of a painful scene, the reappearance of striking events of the day just before the onset of sleep,—each is an instance of perseverance. The perseverance tendency shows considerable variation in different individuals. It is generally strongest immediately after the original presentation, and with the onset of fatigue. Its strength increases with the attention given to the presentation and with the number of repetitions of the latter (exps. 92, 93).

Association.—Apart from perseverance, experiences tend to reproduce themselves by virtue of their "association." If an experience *a* be associated with an experience *b*, the recurrence of *a* tends to reproduce the experience *b* in consequence of the association between them. *Ceteris paribus*, when the association is weak, the tendency to reproduction is slight; when it is strong, the reproduction tendency is great. The revival of presentations is dependent, then, both on perseverance and on association strength.

Memory Images.—Such reproduced experiences, when sufficiently definite, involve "memory images." They contain most of the characters of the original experiences; an auditory memory image, for example, being of high or

[1] See footnote to Chapter III.

of low pitch, a visual memory image being feeble as in the image of a candle, or intense as in the image of an incandescent light. But apart from such differences,—apart, for instance, from variations in intensity,—memory images also vary in vividness. The more vivid a memory image is, the more will it attract and strike the attention, and the nearer will it resemble the reality of an original experience. Under ordinary conditions, however, there is always something wanting in the re-presentation of memory images, which prevents them from being confused with presentations (exps. 92, 93).

The Kinds of Imagery.—There are wide individual differences in the vividness of memory images. Some persons declare that the memory images which they can produce at will are as vivid as those which occur immediately after the original presentation; but such experiences are uncommon.

It is well known that various kinds of imagery are developed to very different extents in different people. Whereas some possess especially vivid visual imagery, others excel in auditory or in kinæsthetic imagery. Some can imagine a scene in all its original colouring; the visual memory images of others are entirely colourless or almost wanting. Some dream vividly of tastes and odours, some can call to mind tactual experiences; whereas in others gustatory, olfactory, and tactual images are very rare. Probably no one is absolutely devoid of any of these kinds of imagery, unless he have been deprived from birth (or within his first few years) of the sensory experiences on which they respectively depend. All our evidence goes to show that exercise, dependent on interest and education and heredity, plays the most important part in selecting the predominant type of imagery.

In the case of most of us, our everyday images are a blend of several kinds of imagery. Several methods, however, have been employed in the laboratory to determine the predominant kind in a given individual. According to

10

one method, he writes down a list, first of objects which possess well-marked colours, next of objects which are characterised by sounds, and so on; devoting the same time, *e.g.* five minutes, to each of these groups. Those individuals in whom, for example, auditory imagery is most strongly developed will be found to write down a far longer list of words which have sounds connected with them than will be done in the same time by folk in whom this imagery is less developed.

Another method of testing the kind of imagery is by learning. Several groups of twelve letters are prepared, each twelve being printed on a separate card in three vertical rows. In a certain number of experiments, the twelve letters are twice read through by the subject, in some experiments with or without movements of his lips, in others silently or aloud. In other experiments, the letters are not exposed, but are only heard as they are read by the experimenter. The reading of the letters is regulated so as to occupy a constant time, say ten seconds. At a given time, say twenty seconds, after each exhibition of a card of twelve letters, the latter are reproduced by the subject, and a careful record is taken of the percentage of his correct replies and of the nature of his mistakes, according to the conditions of learning.

The more pronounced be the visual imagery of the individual and the less pronounced his auditory imagery, the more successfully will he reproduce what he has silently seen, rather than what he has heard. On the other hand, auditory imagery will be most assisted by hearing the letters or by declaiming them while reading; and kinæsthetic imagery will be most assisted by movements of the lips and glottis. The imagery of the predominantly visual type will be little affected, if, while reading the letters, he utter a prolonged vowel, say, *ah*. The imagery of the auditory type, on the contrary, will be thereby placed at a distinct disadvantage.

Some instructive results are also afforded by an examination of the mistakes in reproduction made by different individuals. In the predominantly visual type letters of like appearance, in the predominantly auditory type letters of like sound are liable to be reproduced in the place of those actually presented. Individuals, in whom kinæsthetic imagery is especially developed, feel a tendency to speak or to sing during reproduction; they confuse letters with others requiring similar articulation. Those in whom auditory imagery is developed hear the letters sounding during reproduction, and for this reason often tend to make fewer mistakes with vowels than with consonants. In those whose imagery is of the visual kind, on the other hand, consonants are revived just as easily as vowels; an image of the entire card of letters stands vividly before them, from which they can reproduce the letters diagonally or in any other order as requested. This can only be achieved imperfectly and with the greatest difficulty in the case of the auditory type of imagery, where, of course, the letters are revived successively.

Those in whom one or other of these three kinds of imagery is especially developed, are sometimes called "visiles," "audiles," or "motiles." Cases are on record in which, owing to organic or to merely functional disorder, one kind of imagery completely vanishes, and another is successfully cultivated to take its place. So, too, in the course of prolonged experimental work on memory, subjects have noted that the kind of imagery which they employ is liable to change. From general inquiries it appears that painters and women have especially vivid visual imagery, that imagery is particularly vivid in childhood, and that the visual type is rare among men who are engaged in scientific work. But the data at our command are not precise enough for further generalisations. We know little or nothing of the minor individual variations in imagery which must in part be responsible for proficiency in special memories, *e.g.* for names, faces, or

numbers. Nor have we any introspective data of value from those rare individuals who declare that they are totally devoid of any form of imagery.

Memory After-images.—A distinction has been sometimes drawn between memory images and "memory after-images." This is based principally on the time, the course, and the vividness of their respective appearance. Memory after-images, sometimes called "primary" memory images, occur almost immediately after the attentive perception of an object, and are usually far more vivid than the subsequent memory images.

Care must be taken not to confuse memory after-images with the positive after-images, which are due to persistent sensory processes. When we contrast these images in the case of vision, we note that the sensory after-image follows, while the memory after-image is independent of movements of the eyes, and that the sensory after-image is projected externally while the memory after-image is located internally; and there are other less striking differences (exps. 92, 93).

Like many sensory after-images, however, the memory after-image undergoes fluctuations. An appreciable interval elapses before it first appears, it rapidly gains its maximal intensity and vividness, after which it gradually fades. In the case of the visual image it waxes and wanes perhaps several times per second; while from time to time it vanishes altogether for a few seconds. Finally, it disappears, after a period which varies usually from thirty seconds to several minutes, according to the individual and the nature and duration of the presentation. These fluctuations are readily studied by careful introspective analysis, and by the use of suitable apparatus whereby the observer can by pre-arranged signals record the changes in periodicity or vividness of the memory image (cf. exp. 148).

[*Experiments on the Fading of Images.*—It is a familiar fact that as time goes on, the memory image of a past

experience which we are able to revive becomes increasingly fainter. Attempts have been made to study this process of fading by various experimental methods. In some investigations the original presentation has been a given colour or a given brightness, in others a line of definite length, or a geometrical figure, or a tone of known pitch, or a given time interval, or a touch upon the skin in a definite spot. After varying intervals of time, the observer is asked to reproduce this presentation; or a series of presentations is successively or simultaneously given, some of which are nearly, and others are exactly, like the original. The accuracy with which the observer is able to reproduce or to identify the original presentation, is taken as a measure of the vividness of his memory image after the lapse of a given interval of time.

These investigations have led to the most discordant results. Some workers have found a fairly simple logarithmic ratio between the accuracy of memory and the length of time elapsing since the original presentation, while others have failed to find evidence for any such relation. Some have observed a tendency to error of judgment in one direction, while the precisely opposite tendency has been maintained by others.

These and other discrepancies are but the natural result of the use of non-comparable methods, all directed to the investigation of the same problem, despite the fact that they involve the action of different psychical processes, or of the same processes in different degrees of activity. In some of the experiments, for example, to which we have just referred, the observer is required to produce his original experience, while in others he has merely to choose and to recognise the original among a number of later presentations which are given to him by the experimenter.

But even within the limits of any one of the above-mentioned experiments, there are important differences in the behaviour of different observers, or of the same

observer at different times; all of which require the most careful investigation and differentiation, before the data obtained can be employed to throw light on the course and nature of the memory image. One observer, for instance, will preserve a relatively passive attitude in the interval between the original presentation and its reproduction; another will use every conceivable device to keep the memory image (or some semblance of it) before him during that interval. There will be chance and individual variations of attention. There will be apparent differences, which are only accidental owing to insufficient data and excessive variability.]

[*Comparison without Imagery.*—A yet more important objection may be urged against these experiments, namely, the neglect of the fact that identification is possible in the absence of any recognisable memory image. An experience may be judged as identical with or different from a previous experience, not on the ground of a careful comparison of the memory image of the former with the latter experience (or its memory image), but because the general "situation" is felt to be the same or different in the two cases. The transition from identification by the aid of definite imagery to identification owing to a vague resembling situation occurs to nearly every one who has had practice in such experiments. From the former method, involving a laborious and often uncertain judgment, he passes insensibly to the latter, whereupon his verdict flashes forth spontaneously and unhesitatingly.]

[*Influence of Time and Speech on Imagery.*—There can, however, be no doubt that in course of time the influence both of the situation, as we have called it, and of the true memory image becomes impaired, at first rapidly, later more slowly, and that they suffer in loss of accuracy and vividness. There are certain effects of time upon the memory image which are specially noteworthy. It seems, for instance, that when we retain the memory image of a tone,

we are apt voluntarily to sharpen it, owing to a belief that as it grows dimmer it is also growing flatter (page 32). We are also liable to vary the shade of a given grey in the effort of preserving a memory image of that presentation, for we may have judged the original grey by a vague verbal standard, and we may attempt to revive it by recollecting that the original presentation was considered "bright" or "rather dull" or "very dark." Such verbal standards or symbols clearly play a most important part in our daily life. Indeed, they may prevent a given impression from ever passing into complete oblivion. Thus at the time of presentation we are wont to note that a friend's hair is silvery white, or that an oblong is the size of a domino. Ultimately we come to fix very many of our experiences by means of such purely verbal associations.

Indeed, the more cultured the individual, the more he comes to rely on words, especially on abstract words, rather than on the imagery of concrete objects. To such an extent may this use of internal language predominate, that the individual ultimately almost completely loses the more elementary forms of visual, auditory, or other imagery.]

The Classification of Associations.—The revival of memory images, save in so far as it is the result of perseverance, is dependent on association. The nature of the associations between our experiences has been studied by various experimental methods. According to one method, which we may term the "serial method," the subject begins with a given word, writes down the word which it immediately suggests, then writes down the word immediately suggested by the second word, and so on for a given length of time. According to another, the "reaction method," a printed word is exposed, whereupon the subject instantly declares the first word or idea which occurs to him; and a large number of replies are collected by successively exposing a long series of such words. A study of the pairs of associated

words, thus obtained, has led to various classifications of associations, of which the following is an example:—

Similarity	in meaning	co-ordination	*e.g. baby—infant.*
		superordination	*e.g. soldier—man.*
		subordination	*e.g. man—soldier.*
		contrast	*e.g. peace—war.*
	in sound	in letters or syllables	*e.g. port—porter.*
		in rhyme	*e.g. fight—kite.*
Contiguity	in time	causal	*e.g. lightning—thunder.*
		verbal	*e.g. one—two, snow—snowball.*
	in space		*e.g. handle—lock.*

In these reaction experiments, "false" associations occasionally occur, a word being returned in which no association whatever can be traced with the presented word. By experimentally varying the interest of the subject at the moment the word is exhibited, very different answers can be obtained from him at different times to the same word. Sometimes the subject merely repeats the presented word, or he reacts with a word which has been already presented to or returned by him in a previous reaction. Sometimes, owing to perseverance, a word is returned or tends to return again and again (exp. 94).

The classification of answers is possible only after an appeal to the subject's introspection. For example, the associated pair *might—right* may be the result of association by contrast in meaning, by similarity in sound, or by contiguity in time, according as he was influenced by the meaning, the rhyme, or the proverb. So, too, the association *snow—snowball* may depend on contiguity in time (verbal or causal) or space, or on similarity in sound or meaning. In spite of these difficulties, however, such systems of classification have been proved to have practical value. The percentages of answers returned for the various

classes are found to be influenced by fatigue, by drugs, and by pathological disorders of the nervous system. Broadly speaking, the effect of these conditions is to produce an increase in the proportion of associations by similarity in sound and a decrease in the proportion of those by similarity in meaning.

Experiment in Learning.—It is essential that the experimental conditions be as simple as possible at the outset of any psychological investigation. And, in the case of the preliminary experiments in learning, it is particularly desirable that the words or objects which are to be impressed be of the simplest nature, so that the conditions remain as nearly uniform as possible for different individuals and for the same individual at different times. Accordingly, some of the most important experimental results in this field of research have been obtained by the use of practically meaningless stimuli, chiefly stimuli of a visual kind, *e.g.* single letters, numbers, or senseless syllables. Thereby we have been able to eliminate associations by meaning, to arrive at the conditions affecting the sheer retentiveness and reproducibility of a presentation, and to determine the number and course of the associations which are formed among the members of a series of such objects. It is true that the conditions laid down may depart somewhat widely from those which obtain in daily life. But only from such simple beginnings can psychological knowledge advance beyond that stage which had been already reached before the utilisation of experiment.

The Learning and Saving Methods.—The first two methods of experiment which we shall describe are termed the "learning" and the "saving" methods. In the former, a series of meaningless syllables is read through at a prescribed uniform speed, and the readings are repeated until the first correct reproduction can be effected. Note is taken of the number of necessary repetitions. In the saving method, a varying interval is allowed to elapse after the

task has been learned by the learning method. Then the number of repetitions is ascertained in order once more to effect the first correct reproduction. It is compared with the number of previous repetitions. Throughout all these experiments every reading is followed by an attempted reproduction, until a successful result is attained (exp. 95).

The Prompting Method.—In the "prompting" method a series is similarly, but imperfectly, learnt, and the accuracy of reproduction is estimated by the number of times the subject requires to be prompted, in order to effect a perfect reproduction. These three methods have been applied to the learning of sensible material (prose or poetry), as well as to the learning of senseless material (letters or syllables).

The Scoring Method.—The "scoring" method needs somewhat complex apparatus, but yields on the whole more precise information than any of the previous three methods, although each can claim special merits. In this method, a series of syllables is read a prescribed number of times, usually in trochaic rhythm; that is to say, the successive syllables are learnt in pairs, the first member of each pair being strongly accented by the reader. The number of repetitions, however, is relatively small, and is always insufficient for a perfect learning. An interval of varying length now elapses; whereupon the accuracy of reproduction is tested by re-exhibiting in various order the first members of these pairs, the subject being required to reproduce the corresponding second members. The "score" is determined by the proportion of right answers, the failures by the proportion of wrong answers or of no answers at all, in the entire series. Apparatus may be introduced in this scoring method, which permits of measurement of the "reproduction time," *i.e.* the interval elapsing between the recognition of the first member of the pair, when it is re-exhibited, and the reproduction of its fellow. The reproduction time for effecting a score is called the "scoring time" (exp. 96).

[*Comparison of the Learning and Scoring Methods.*—In the following study of the chief results obtained by experimental methods, we shall have to refer most frequently to the learning, saving, and seoring methods. In each of these it must be remembered that we are studying the reproducibility, not of a single, but of numerous, associated members of a series; for the eonditions of reproduction are too eomplex to permit of the study of the reprodueibility of individual syllables. In the learning and saving methods, the results express the number of repetitions just neeessary to effeet perfeet repetition of a series of syllables. In the seoring method, as we shall immediately see, the seore gives a measure of the mean tendeney to reproduetion, possessed by the first syllables of the pairs in the series. For, when the effects of perseveranee ean be eliminated, what the scoring method tests is the mean tendency of the syllables *a*, *c*, *e* . . ., to reproduee respectively the syllables *b*, *d*, *f* . . ., with which they have become associated.

In the learning and saving methods, the series is treated as a whole, and the data are complieated by the formation of associations between *b* and *c*, *d* and *e*, ete., and, as we shall later see, by assoeiations between more distant members. Further eomplieations are introdueed in the learning and saving methods owing to the fact that only a part of the series is reprodueed, so long as the learning is ineomplete, and thus reeeives more frequent repetition than the rest; also owing to the possibility that several syllables are simultaneously in the field of vision while reading.

The fatigue, whieh is involved in repeating long series of syllables by the learning or saving method, until the first eorrect reproduetion is effeeted, beeomes much redueed in the seoring method, where reproduetion may be tested after any arbitrary number of readings.

The results obtained by the learning and saving methods are liable to be enormously influenced by the distribution of individual assoeiation strengths. The accidental presenee of

one or two exceptionally weak associations, in a series learnt by these methods, must materially increase the number of repetitions necessary for a correct reproduction; whereas, in the scoring method, the score, which may be taken at any time, is independent of the extent to which certain associations may lie below the threshold, and merely measures the number of associations which are effective at the moment.

Many of the drawbacks of the learning and saving methods, to which we have drawn attention, are in some degree avoidable by employing a "modified" learning and saving method, in which, as in the scoring method, the syllables are successively exposed before a window, are read in trochaic rhythm, and are learnt in pairs. This arrangement allows us experimentally to study the effect of replacing one or more pairs of syllables by others. By learning series which are altogether new, side by side with series, members of which are partly old and partly new, the reliability of the value of the saving time may often be materially increased.]

Other Methods.—Lastly, there are two methods in which recognition can be experimentally studied apart from reproduction. The first of these is by "selection," the subject choosing the learnt object from among a number of objects subsequently exhibited. The second is by the use of "identical series." Here the entire series, which has been imperfectly learnt, is re-exhibited, and the subject, wholly ignorant of this procedure, is asked whether a change has or has not been effected.

Relation between Scoring Time and Association Strength.—By means of the scoring method, it can be shown that those pairs of syllables, the members of which possess the most lasting (or strongest) associations, also give the quickest scoring times. A given number of series of syllables is read until they have been learnt imperfectly. Each series is twice tested, first twelve minutes and again twenty-four hours after the last reading. The scoring times are classed

acccording as their values are greater or less than 2000^{σ}. It is found that those pairs of syllables, which at the earlier reproduction had given scoring times less than 2000^{σ}, yield 66 per cent. of the scores at the later reproduction, while those pairs, which at the earlier reproduction had given scoring times greater than 2000^{σ}, yield only 32 per cent. of the scores at the later reproduction. Thus there appears to be a correlation between the reproduction times and the durability of associations, and hence presumably between the former and their strength.

An increase in average scoring time need not in all circumstances imply a decline in general reproductive tendency. For, as with successive readings fresh individual associations in the series rise above the threshold, they naturally tend to give longer scoring times than the easier and previously effective associations, and thus may raise the mean scoring time.

Further, under certain conditions the reproductive tendency may increase, in spite of an unchanged average scoring time. When, for example, an increasing number of repetitions ultimately fails to shorten the scoring times beyond a certain limit, it would be rash to conclude that further repetitions produce no change in the reproductive tendency or durability of associations.

Influence of the Length of the Series.—The number of individual words or syllables, which can be perfectly learnt after one reading by the learning method, is found to depend on their nature. One investigator reports that after a single reading he can immediately reproduce seven disconnected words, or eighteen words of a poem, or twenty-two prose words; another finds that he can learn in a single reading eleven figures, or nine disconnected words, or seven letters or senseless syllables.

The influence of the number of senseless three-letter syllables on the number of repetitions needed for immediate reproduction by the learning method, has been investigated

in the following way. At each sitting, nine series of twelve syllables, or six series of sixteen syllables, or three series of twenty-four syllables, or two series of thirty-six syllables, are read at a uniform speed, each series being repeated until the first correct reproduction is effected. The following is the average of results obtained after a considerable number of such sittings:—

Number of syllables in series . .	7	12	16	24	36
Number of repetitions needed . .	1	16·6	30	44	55

The strength of the associations, which are effected between individual members, by learning such a series of syllables, must increase with successive repetitions. After the first reading, very few associations have the requisite strength or force to be effective. With subsequent readings, first some, later others, rise above the threshold and thus become effective. Finally, a certain mean strength of all associations is reached, which first allows of the first correct reproduction. The greater the number of syllables in the series, the greater must be the fatigue and the less concentrated the attention, in later repetitions and reproductions. Hence, in the learning method, the mean association strength of the members of a long series must be greater than that of the members of a short series, in order just to effect a correct reproduction.

[Let us now turn to a somewhat similar investigation conducted by the scoring method. In a set of experiments lasting twenty-four days, two series each of twelve syllables and two each of eighteen syllables are read a certain number of times daily. The series read are entirely new each day. The number of repetitions of each series is for some series small (seven, eight, or nine), for others large (twelve, thirteen, or fourteen). Care is taken that the subject is unaware how many times the presented series will be repeated before reproduction is required. The position of the long and short series relatively to one another is

changed daily. Five minutes elapse between the last reading and the re-exhibition of the syllables for reproduction. The results are as follows, r representing the number of scores in ratio to unity, $T_r < 2000^\sigma$ being the absolute number of those scoring times which are less than two seconds:—

	Few Repetitions.		Many Repetitions.	
	r	$T_r < 2000\sigma$.	r	$T_r < 2000\sigma$.
Twelve-syllable series .	0·60	33	0·71	40
Eighteen-syllable series .	0·47	21	0·69	27

Clearly the more frequent readings produce a very much greater effect on the longer than on the shorter series. In other words, the number of associations, which after a few repetitions are almost ready to rise above the threshold and to become effective, is considerably greater in longer than in shorter series.]

[*Influence of the Position of Syllables, and of Accent and Rhythm.*—When a series of ten or twelve members is learnt by the prompting method (page 154), it is seen that the impression made by the different members varies according to their position in the series. The following experimental data indicate that the first member of the series is most easily remembered, that the second and last members follow next:—

Order of Word in Series.		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Number of 'prompts'	in 12-word series	0	11	21	13½	35	36	36	29½	43	37½	34	11
	in 10-word series	0	3	6	9	23	24	31½	25	23	5½	...	...

The learning of such a series is therefore comparable to the building of a bridge, the ends of which are begun first, the builder working towards the middle.

That the position of syllables within a series and their accent have a most important influence on learning, is shown by the following experiment. Pairs of twelve syllable-series, each series having previously been learnt in trochaic rhythm, according to the modified learning method (page 156), are intermixed, rearranged, and subsequently relearnt. Let us designate a given pair of series:—I_1 I_2 I_3 . . . I_{12}, II_1 II_2 II_3 . . . II_{12}. Different pairs are now arranged in different ways. In some the original accent is retained, while the order of the syllables is changed, *e.g.* I_1 II_{10}, $I_{11}II_8$, I_9 II_6, I_7 II_4, I_5 II_2, I_3 II_{12}, or, by a different plan, I_{11} II_{12}, I_9 II_{10}, I_7 II_8, I_5 II_6, I_3 II_4, I_1 II_2. In others the original pairs (save the first) and the original accents are maintained thus—I_{11} II_{12}, I_9 I_{10}, II_7 II_8, I_5 I_6, II_3 II_4, I_1 I_2. In three other pairs these orders are reversed, so that the originally accented syllables now become unaccented, and *vice versâ*, *e.g.* I_2 II_{11}, I_{12} II_9, I_{10} II_7, I_8 II_5, I_6 II_3, I_4 II_1. It is found that, when these various derived series are relearnt twenty-four hours after the learning of the original series, by far the greatest saving is effected by that arrangement in which the original pairs and accents are preserved.

The scoring method shows clearly that associations are formed by virtue of position. Not infrequently when a wrong syllable is given, it is found to have occurred in a corresponding place in a series which had been learnt some time before. There appear to be wide individual differences in the liability of subjects to associations of this kind.

Most subjects find it difficult, if not impossible, to avoid rhythmisation, when they are confronted with the task of learning a series of senseless syllables. They tend spontaneously to develop rhythmic movements of the head, trunk, or limbs, and they find that a favourable rhythm, just

as a favourable speed of reading, exists for them, which proves the most economical method of learning.]

BIBLIOGRAPHY.

T. Fechner, *Elemente d. Psychophysik*, Leipzig, 1860, ii. 468. H. Ebbinghaus, *Ueber das Gedächtniss*, Leipzig, 1885. H. K. Wolfe, "Untersuch. über d. Tongedächtniss," *Philosoph. Stud.*, 1886, iii. 534. H. Münsterberg, *Beiträge zur experimentelle Psychol.*, 1889–92, Hft. 1–4. G. E. Müller and F. Schumann, "Experimentelle Beiträge zur Untersuchung des Gedächtnisses," *Ztsch. f. Psychol u. Physiol. d. Sinnesorgane*, 1894, vi. 81, 257. G. Aschaffenburg, "Experimentelle Studien über Associationen," *Psychol. Arbeiten*, 1895, i. 209 ; 1897, ii. 1. J. Cohn, "Experimentelle Untersuchungen über d. Zusammenwirken d. akustisch-motorischen u. d. visuellen Gedächtnisses," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1897, xv. 161. G. E. Müller and A. Pilzecker, "Experimentelle Beiträge zur Lehre vom Gedächtniss," *ibid.*, Ergänzungsbd. i. 1900. G. M. Whipple, "An Analytic Study of the Memory Image and the Process of Judgment in the Discrimination of Clangs and Tones," *Amer. Journ. of Psychol.*, 1901–2, xii, xiii. A. Binet, *L'Étude expérimentale de l'Intelligence*, Paris, 1903. E. Claparède, *L'Association des Idées*, Paris, 1903. H. J. Watt, "Experimentelle Beiträge zu einer Theorie d. Denkens," *Arch. f. d. ges. Psychol.*, 1905, iv. 289.

CHAPTER XIII[1]

ON MEMORY (*concluded*)

The Rate of Forgetting.—The saving method affords a means of studying this subject. The following is a record of 163 experiments, nearly all of which consist in learning eight thirteen-syllable series and in re-learning them at a prescribed rate of reading after a varying interval, until two consecutive perfect reproductions are effected; the economy of time, spent in re-learning, being in each instance noted.

Re-learning after x hours. $x=$	Percentage of Time Saved.	Percentage of Time Lost.
0·3	58·2	41·8
1·0	44·2	55·8
8·8	35·8	64·2
24	33·7	66·3
2 × 24	27·8	72·2
6 × 24	25·4	74·6
31 × 24	21·1	78·9

These experiments are admittedly very crude, and it would be rash to infer from them that one-half of the matter is forgotten after the first half-hour, two-thirds in

[1] See footnote to Chapter III.

nine hours, three-quarters after six days, or four-fifths after a month. Yet there can be no doubt that in the process of forgetting a very great initial fall of memory occurs, followed by losses which become increasingly less.

That the most rapid fall of memory occurs immediately after learning is also shown by the fact that, when associations which have just been formed are compared with others ten minutes old, there is a far greater difference in the number of scores than when associations ten minutes old are compared with others which are twenty-four hours old. Now the tendency towards reproduction in the scoring method is the outcome of perseverance as well as of association strength. It is perhaps mainly because of the rapid falling off of perseverance (which is most effective in immediate memory) that the youngest associations suffer more at the hands of time than older ones.

Retro-active Inhibition.—On the other hand, time has a favourable effect on associations, in that it allows of their consolidation. There is reason to believe that the act of forming one association *c–d*, just after the formation of another association *a–b*, inhibits the latter. This "retro-active inhibition" is yet another cause of the greater difficulty in learning longer than shorter series. It disappears in course of time, whereupon the various associations are better consolidated. The familiar practice of imperfectly learning a task at night and allowing rest to improve the associations by the morning, depends partly on this process of consolidation.

The experimental investigation of retro-active inhibition has shown that, when the learning of a series of syllables precedes by a few seconds the readings of a second series, the subsequent number of scores and of short scoring times of the first series is smaller than when some minutes elapse between the readings of the two series.

Such retro-active inhibition may be likewise demonstrated, when the interval between the last reading and the reproduction is only one or two hours, or even when it is

twenty-four hours. There is also evidence of its action, not only when the second task is similar to the first, but also when it is of a quite different nature. Thus, when four series of twelve syllables, which we may call *A*, are read eight times, and are followed by so close an examination of three pictures as to enable the subject to pass a minute examination on their contents; and when four like series of syllables, *B*, are similarly read, the like interval however between reading and reproduction now being as restful as possible; the score and the average scoring time are found to be 0·24 and 2950^σ in series *A* and 0·56 and 2490^σ in series *B*.

Retro-active and Remote Association.—So far we have chiefly dealt with "principal" associations,—the associations formed between the immediately consecutive members of a series in a forward direction. We have now to consider the evidence in favour of the existence of certain "subsidiary" associations, more particularly of associations formed in the reverse direction, and of forward associations formed between not immediately consecutive members of a series. These we shall respectively call "retro-active" and "remote" associations.

Six series, each of sixteen syllables, are learnt, which we may designate as I_1 I_2 I_3 . . . I_{16}, II_1 II_2 II_3 . . . II_{16}, III_1 III_2 . . . III_{16}, IV_1 . . . IV_{16}, V_1 . . . V_{16}, and VI_1 . . . VI_{16}. Twenty-four hours later, six derived series are learnt, and the saving of time is noted by the saving method. These derived series are prepared from the above in one of five different methods, *a*, *b*, *c*, *d*, and *e*; but on any one day all six of the derived series are prepared by the same method.

In method *a*, alternate syllables are omitted, so that the six series run:—

(i.) I_1 I_3 . . . I_{15} I_2 I_4 . . . I_{16}
(ii.) II_1 II_3 . . . II_{15} II_2 II_4 . . . II_{16}
. . . .
. . . .
. . . .
(vi.) VI_1 VI_3 . . . VI_{15} VI_2 VI_4 . . . VI_{16}

In method *b*, two consecutive syllables are removed, so that the first of the six series runs :—

$I_1\ I_4\ I_7\ I_{10}\ I_{13}\ I_{16}\ I_2\ I_5\ I_8\ I_{11}\ I_{14}\ I_3\ I_6\ I_9\ I_{12}\ I_{15}$

In method *c*, three consecutive syllables are removed. In method *d*, seven consecutive syllables are removed, the first two series running thus :—

(i.) $I_1\ I_9\ II_1\ II_9\ III_1\ III_9\ IV_1\ IV_9\ V_1\ V_9\ VI_1\ VI_9\ I_2\ I_{10}\ II_2\ II_{10}$

(ii.) $III_2\ III_{10}\ IV_2\ IV_{10}\ V_2\ V_{10}\ VI_2\ VI_{10}\ I_3\ I_{11}\ II_3\ II_{11}\ III_3\ III_{11}\ IV_3\ IV_{11}$

In method *e*, the position of the first and last members of each of the original six series is alone retained, the other fourteen members of each series being arranged quite in haphazard order.

The following results have been obtained :—

Method.	Learning Time of Original Series.	Learning Time of Derived Series 24 Hours later.	Percentage Saved.
a	1275″	1138″	10·8
b	1260″	1171″	7·0
c	1260″	1186″	5·8
d	1268″	1227″	3·3
e	1261″	1255″	0·5

Method *e* was expressly devised to demonstrate that the saving is not due to familiarity with the syllables of the original series.

From these data the conclusion has been drawn that, in learning a series of presentations, associations are formed not only between immediately consecutive members, but also between those which are not immediately consecutive,

the strength of this remote association diminishing with the distance of the members from one another.

Similar experiments have been conducted with the object of proving retro-active, *i.e.* backward association. It has been found that while 33·3 per cent. is saved when a sixteen-syllable series is relearnt in the same order twenty-four hours later, there is still a distinct saving, namely, one of 12 per cent., when another such series is relearnt after a like interval in completely reversed order, $I_{16}\ I_{15}\ I_{14}\ \ldots\ I_1$, and that there is even a saving of 5 per cent. when the derived order is obtained both by reversal and by the omission of alternate syllables, $I_{16}\ I_{14}\ I_{12}\ \ldots\ I_2\ I_{15}\ I_{13}\ \ldots\ I_1$.

In these experiments the possibility of simultaneous vision of more than two consecutive syllables during reading was not adequately safeguarded as it is in the scoring and in the modified saving methods. The results are further complicated by the undoubted tendency of any given syllable in the derived series to reproduce the consecutive syllable of the original series; by virtue of which that consecutive syllable would continue to be held in a certain "readiness," and would in consequence be more easily learnt, the earlier it actually appeared in the derived series. Yet a closer examination of such complications and the results of subsequent more laborious experiments, in which these objections have with some success been eliminated, leave room for no doubt as to the formation of retro-active and remote associations.

The Behaviour of Related Associations.—We have just alluded to the tendency of a syllable to be held in "readiness," when another syllable, with which it has been previously associated, is subsequently learnt in association with a different syllable. This tendency deserves to be examined more closely; it has been also termed the "strengthening of related associations." When a syllable *a*, which has been already firmly associated with a syllable *b*, is presented with *c*, the association *a–b* is strengthened, *b* either being

actually recalled, or merely being held in readiness, so that subsequent learning of *a–b*, as evidenced by the number of scores and the brevity of scoring times, is facilitated by the act of learning *a–c*.

[This concomitant increase in related association strength has been found to vary in different individuals. It is most manifest when the association *a–b* is already of fair strength, before *a* and *c* are presented, and it differs therein from the action of an increased number of repetitions, which improve the weaker at least as much as the stronger associations. Its effect is also dependent on other factors, *e.g.* the shortness of the interval elapsing between the last reading of *a–c* and the testing of the improvement of the association *a–b*. But into these and other conditions we cannot enter here. When, on the other hand, the association *a–b* has been but imperfectly formed, or more especially when it has not been formed at all, the formation of an association *a–c*, so far from being favourable, is actually antagonistic to the subsequent formation of the association *a–b*. That is to say, while the readings of *a–c* facilitate the subsequent reconstruction of the previously *well-formed* association *a–b*, they inhibit the subsequent formation of the association *a–b*, if it be practically or altogether *non-existent* at the time of the formation of *a–c*.]

[*Unconscious Association.*—In connection with the concomitant strengthening of related associations, the following experiment is of considerable interest. Six series of sixteen syllables, $I_1 \ldots I_{16}$, $II_1 \ldots II_{16}$, etc., are repeated a definite number of times. Twenty-four hours later, six derived series are learnt in the following order:—

(i.) $I_1\ I_3\ I_5 \ldots I_{15}\ II_1\ II_3\ II_5 \ldots II_{15}$
(ii.) $I_2\ I_4\ I_6 \ldots I_{16}\ II_2\ II_4\ II_6 \ldots II_{16}$
(iii.) $III_1 \ldots III_{15}\ IV_1 \ldots IV_{15}$
(iv.) $III_2 \ldots III_{16}\ IV_2 \ldots IV_{16}$
(v.) $V_1 \ldots V_{15}\ VI_1 \ldots VI_{15}$
(vi.) $V_2 \ldots V_{16}\ VI_2 \ldots VI_{16}$

It is found that the second, fourth, and sixth series are learnt more easily than the first, third, and fifth series.

Two explanations of this result are possible; and one is undoubtedly true, namely, that the learning of I_1 I_3 I_5, etc., in (i.) brings into readiness the syllables I_2 I_4 I_6, etc., and so facilitates the subsequent learning of (ii.). But there may be a further explanation. It is conceivable that the successive bringing of the syllables I_2 I_4, etc., into readiness unconsciously lays down associations or reinforces the previous remote associations between them. This possibility has suggested very long and laborious experiments, the object of which has been to determine whether the successive bringing of syllables into readiness causes them to become unconsciously associated with one another. The evidence is by no means decisive, but it is perhaps in favour of the unconscious formation of such associations.]

Initial and Group Reproduction.—If syllables *a*, *b*, *c*, etc., be learnt in groups of three in anapæstic measure (◡◡–), *a* tends to be reproduced more frequently than *b*, when the accented member *c* is subsequently presented. There exists a tendency to "initial reproduction." So, too, when a series has been learnt in trochaic measure (–◡), the preceding accented member is reproduced much more often than the following accented member, when any second or unaccented member is presented. In this case the tendency to initial reproduction is perhaps complicated by the undoubted tendency of any member of a group to revive the whole group. Our experience in daily life familiarises us with this latter tendency, the word "gables," for instance, reviving the whole phrase, "the house with the seven gables."

[*The Independence of Subsidiary and Principal Associations.*—Such retro-active associations are more evident in recently than in earlier learnt series. By the scoring method it has been found that, when five minutes elapse between the last reading and reproduction, of forty-two

wrong answers there are seven in which the last syllable of the previous pair, instead of the immediately following syllable of the same pair, is reproduced; whereas there are no such wrong answers in other learnt series, when twenty-four hours are allowed to elapse. Even if the number of readings in the two experiments be so arranged that the scores (*i.e.* the strengths of the principal associations) in one series are the same five minutes after learning as they are in another series twenty-four hours after learning, the retro-active associations of the latter are always fewer. In other words, retro-active associations wane more rapidly than principal associations.

A similar want of correlation is found between the strengths of remote and principal associations. Increased repetition is found to have a much less improving effect on remote than on principal associations.]

[*Mediate Association.*—While there is good reason for believing in the existence of remote association, the evidence in favour of what is called "mediate" association is unquestionably very weak. Mediate association occurs if, when *a* is associated with *b*, and *b* later with *c*, the subsequent presentation of *a* yields *c* without the reproduction of *b*. Remote association, on the other hand, is merely an example of association by temporal or spatial contiguity. In the series *a*, *b*, *c*, *c* follows on *a*, forms part of *a*, *b*, *c*, and is therefore associated with *a*. In mediate association, the presentations do not occur in this way. The association between *a* and *b*, and that between *b* and *c*, are separately formed at different times; *a*, *b*, and *c* do not belong to a single series.

The first experimental inquiry into the existence of mediate association was conducted in a somewhat crude and unconvincing fashion. Three series of words were prepared, namely (a) German words; (b) their equivalents in Japanese characters; and (c) the same Japanese words written in Roman characters. For brevity's sake let us call these

three groups of presentations *a*, *b*, and *c*. Cards were exposed in irregular order before the subject, first those containing any *b* beside its corresponding *c*, and next others, in equal number, showing any *a* beside its *b*. Thereupon, the subject was asked if he had observed any relation between the *a–b* cards and the *b–c* cards, and the experiment was continued only if he declared that he had not observed any relation. Then cards, each bearing any one of the *a* words only, were exhibited, and the subject was asked to state the first word which occurred to him. There were said to be many instances in which he returned the appropriate *c*, without the Japanese character *b* ever having occurred to him.

Later investigators, however, have failed to find similar evidence. It is true that in reaction experiments upon simple association, reaction words and introspective data have been obtained, which seem to show the occurrence of mediate association. But very many of these replies are capable of quite a different interpretation. When, for example, the exhibition of the word *house* yields the reply *marines*, the answer may be due merely to the confusion, through similarity, of *house* and *horse*. We need not suppose that, the word *horse* being associated by verbal similarity with the word *house*, and by verbal contiguity with the word *marines*, we have a case of mediate association between *house* and *marines*.

Such confusion by similiarity is of frequent occurrence, alike in ordinary life (*e.g.* when a child calls an animal by the wrong name, or when a person makes a slip in talking), and in the experimental investigation of memory. If, for example, *A–B* is learnt, and if *a* resembling *A* is later presented, *B* is liable to be produced. This has been called "wrong association by active substitution." Another variety of wrong association, which also comes into play in the just mentioned association experiments, occurs when *A–B* is learnt but *A–b* is reproduced, *b* having

some resemblance to *B*. This has been called "wrong association by passive substitution." These associations by substitution are capable of explaining many of the replies which at first sight appear to favour the play of mediate association.

The fact that the subject is not conscious of the presence of the medial connecting link, until he has given the reaction word, affords no proof that the association of the former with each of the words is physiologically inactive. In daily life, a long time may elapse before the connecting link between two successive thoughts is apparent. Nay, the attention may be so fixed upon the initial or final member of the trio, that the intermediate member fails altogether to effect consciousness. This way of stating the process, however, is very different from the assertion that a direct mediate association is formed between the first and the third.]

The Distribution of Repetitions.—It is a familiar experience that a lesson is better retained when the learning extends over a considerable period of time, than when the task is learnt by the same number of repetitions at a single sitting. The inferior value of accumulated, as compared with distributed, repetitions is at first sight attributable to differences in fatigue, interest, or attention. But the following experiment proves that such an explanation is inadequate.

Thirty-six series of twelve syllables are learnt in trochaic rhythm by twenty-four repetitions distributed in three different ways, namely, over (*a*) three, (*b*) six, and (*c*) twelve days. Thus the series which we shall call *a* are repeated eight times on three consecutive days, the series *b* four times on six consecutive days, series *c* twice on twelve consecutive days. On the fourth, seventh, and thirteenth days, *a*, *b*, and *c* are respectively tested by the scoring method. The research extends over two periods each of fourteen days; in each such period six of series *a*, six of *b*, and six of *c* are

learnt. The eighteen series, a_1–a_6, b_1–b_6, c_1–c_6. are learnt in the following order on different days :—

First	day :	c_1	b_1	c_2	a_1	c_3	b_2	c_4	a_2	c_5	b_3	c_6
Second	„ :	b_1	c_2	a_1	c_3	b_2	c_4	a_2	c_5	b_3	c_6	c_1
Third	„ :	c_2	a_1	c_3	b_2	c_4	a_2	c_5	b_3	c_6	c_1	b_1
Fourth	„ :	$[a_1]$	c_3	b_2	c_4	$[a_2]$	c_5	b_3	c_6	c_1	b_1	c_2
⋮												
Seventh	„ :	c_4	a_4	c_5	$[b_3]$	c_6	c_1	$[b_1]$	c_2	a_3	c_3	$[b_2]$
Eighth	„ :	$[a_4]$	c_5	b_6	c_6	c_1	b_4	c_2	$[a_3]$	c_3	b_5	c_4
⋮												
Twelfth	„ :	$[a_5]$	c_5	b_6	c_6	c_1	b_4	c_2	$[a_6]$	c_3	b_5	c_4
Thirteenth	„ :	$[c_6]$	$[c_1]$	b_4	$[c_2]$	a_6	$[c_3]$	b_5	$[c_4]$	a_5	$[c_5]$	b_6
Fourteenth	„ :	c_5	$[b_6]$	c_6	c_1	$[b_4]$	c_2	a_6	c_3	$[b_5]$	c_4	a_5

The series are enclosed in brackets on the days when they are tested. As the number of series tested on the thirteenth day is unusually heavy, this day's task is lightened by inserting two series which have been already tested; this is also done on the last day.

A pause of about two minutes separates the reading of consecutive series. Each day's experiment lasts about thirty-five minutes. During the whole research seventy-two pairs of syllables are learnt in trochaic rhythm for each of the series *a*, *b*, *c*. The following are the results given by two individuals, *X* and *Y*, r^1 representing the *absolute* number of scores, *Tr* the average scoring time :—

	a		*b*		*c*	
	r^1	*Tr*	r^1	*Tr*	r^1	*Tr*
X	18	2496^σ	39	2213^σ	53	2007^σ
Y	7	2429^σ	31	1570^σ	55	1675^σ

These data clearly show that distributed readings yield

a greater number of scores than accumulated readings. They also show that the cause cannot lie in differences of fatigue or of interest, since the effect is visible both in *b* and in *c*, which only differ by two readings daily. That the average scoring times do not show a proportionate increase in speed is due to the overweighting influence, in *b* and *c*, of associations which are only just above the threshold, and consequently have relatively long scoring times (page 157).

Nor is the superior retentivity of the most distributed readings due to the involuntary revival of the syllables by the subject between the periods of reading. He was carefully instructed not to think of the syllables. Besides, the same results have been obtained in other experiments, where the accumulated repetitions are compared with groups of repetitions which are separated by minutes instead of by days from one another.

The Influence of the Age of Association on the Results of Repetition.—There are probably several factors contributing to produce this result, but evidence points very strongly to the influence of the following. When two associations are of like strength, but of unlike age, repetition increases the strength of the older more than that of the younger association. The importance of this factor is clearly shown in the following experiment.

Two series of twelve syllables (series A_1, A'_1) are each read thirty times. Twenty-four hours later they are tested, one by the saving, the other by the scoring method. Thereupon two new series of twelve syllables (series B_1, B'_1) are immediately read four times, and are tested, one by the saving, the other by the scoring method, one minute after the last reading of each. Then two more series (A_2, A'_2) are thirty times. These are tested on the morrow, after which two series (B_2, B'_2) are read and tested and series A_3, A'_3 are learnt. Thus, except on the first day, four series are read and four are tested daily. Sometimes the test by the saving precedes that by the scoring method, sometimes the contrary

order is observed, so that all differences due to temporal position may be eliminated. Each day's sitting lasts about fifty minutes, the research occupying twenty-one days. The following are the average results :—

Series.	Number of Repetitions to relearn.	r	Tr
A	5·85	0·9	4503^{σ}
B	9·6	2·7	1725^{σ}

In this experiment it will be observed that the associations tested in the A series are twenty-four hours old, and that those in the B series are only about one minute old. The results show that in the younger associations B the mean association strength (as judged by the average scoring times, T_r, and by the average number of scores per series r) is much greater than in the older associations A. Nevertheless the B series require many more repetitions than the A series in order that they may be relearnt. If, now, the A and B series had been learnt so that in the above experiments they gave similar values for r,—if, in other words, the number of original readings of the A and B series had been respectively increased or decreased, so that the mean association strength in A, after twenty-four hours, was equal to that in B, after one minute,—it is clear that the difference between them in the number of repetitions necessary for relearning would have been still greater. Doubtless there are complex factors at work in this experiment as in the last, but the observed differences are quantitatively too great to lead us to any other conclusion than that, when two associations are of equal strength, but of unlike age, repetitions act more effectively on the elder than the younger.

The Influence of Time on Associations of Different Age.—

Yet another factor must be invoked in order to explain the familiar fact that, if a given task be relearnt on successive days by the saving method, until it can on each day be correctly reproduced, the number of repetitions necessary for so doing grows daily less, until ultimately no fresh repetitions are needed at all. We are compelled to assume, that when two associations are of equal strength, but of unlike age, time has a more marked effect on the younger than on the elder association.

[*The Most Economical Method of Learning.*—The experiments on the distribution of repetitions (page 171) have led to a more detailed investigation of the most economical modes of learning a given task. The two modes of learning which have most frequently been compared may be called the "entire" and the "sectional."[1] In the entire method, the material is learnt by reading it completely through time after time. In the sectional method, the material is subdivided, and the subject repeats each section until it is learnt, before passing on to learn the following section (exp. 97).

The factors determining the relative efficacy of these two methods are obviously very complex, and nearly all of them must vary considerably in different individuals. On the whole, however, the experimental evidence is in favour of entire learning, sectional learning proving less economical the greater the number of sections into which the task is divided.

It will be noticed that in the entire method there is a total absence of those unnecessary associations, between the end and the beginning of the same section, which are inevitably formed in sectional learning. When the material is sensible, the entire method enables a general impression of the whole to be obtained, while every subsequent reading, by improving the learner's grasp of the contents, suggests fresh rational aids to memory. In the sectional method, attention is more likely to wane during successive repetitions

[1] The "entire" is also known as the "global" method.

than in the entire method. On the other hand, the subject gains confidence by the feeling that he is already mastering at least a part of the task, while in the entire method success looms vaguely and indistinctly before him. A mixed method of learning has been investigated in which the matter is learnt in three sections, and after each section has been learnt the matter is recited afresh from the beginning. This method, although more economical as regards immediate memory, is surpassed by the entire method in respect of retention.

When the task consists of very unfamiliar matter, requiring undue strain of attention,—when, for instance, adults learn series of foreign words, or when children learn series of senseless syllables,—the fatigue involved in the entire method may be so great that the needful repetitions are more numerous than in the sectional method; yet the series is better retained. For like reason, a subject *A*, who finds considerable difficulty in daily learning four series of syllables in trochaic rhythm, two by the entire, two by the sectional method, gives the following relative scores and short scoring times, as compared with another subject *B*, to whom the task comes more easily:—

Subject.	Entire.		Sectional.	
	r	$T_r < 2000^\sigma$	r	$T_r < 2000^\sigma$
A (average of twenty days)	0·30	9	0·44	23
B (average of first eighteen days)	0·31	21	0·36	21
,, (average of second eighteen days)	0·31	16	0·23	11

There is some evidence that continued practice at one or other of these methods materially alters the relation

between them. The subject, however, is too complex to be pursued further here. Individual differences in the relation of subsidiary to principal associations, in liability to retro-active inhibition of associations, in the play of perseverance and of consolidation changes, besides the factors which have been just enumerated, must make a precise investigation of the subject extremely difficult.]

Improvement in Mechanical Learning.—We have already pointed out (page 153) how necessary it is to begin the experimental study of memory with simple meaningless material. Yet even under these conditions introspection shows that the mental processes are very complex and inconstant until practice has brought about a uniform method of learning. At the outset, the novice is disturbed by diverse extraneous ideas which have in turn to be controlled. He makes purposeless movements of the eyes, limbs, and face, many of which, being the outcome of an endeavour to restore a flagging attention, are in themselves distracting. Indeed, his consciousness is continually toned with displeasure, he is continually changing his method of learning, now laying stress on the absolute position of syllables, now marking the rhythm, now changing the imagery employed. But with increasing practice, he discovers the best method of learning. His attention is no longer divided, untoward thoughts and unnecessary movements cease, his available fund of mental energy is wholly devoted to the task. His control over the initial, useless and harmful, factors gives him a pleasant feeling of mastery, spurring him on to further success. Any mnemonic helps on which he had at first been prone to rely are by now discarded. His "general attitude" to the work becomes increasingly favourable. He yields more and more completely to sheer mechanical memory.

Such is the practice which must needs be obtained before experiments with meaningless matter can give truly reliable results. Yet even under these conditions the

attention must change somewhat with different readings. For example, during the first reading of difficult material it is almost wholly concentrated on the pronunciation of the presented matter. Only in later readings is it given up to stamping in, to impressing, the material.

[*The Influence of Speed of Reading.*—The type of imagery employed is liable to alter with change in the rate of reading. There is some evidence that auditory imagery and rhythmic effects usually preponderate in rapid reading. The most effective speed of reading is naturally dependent on the difficulties of the material and on the kind of efficiency that is desired. It appears that, within certain limits, slow readings of senseless syllables give a greater number of scores, but a smaller percentage saving, than quicker readings in greater number during the same period of time. But so far we are without sufficient experimental data to speak at all precisely on the relations between the rate of reading, the rate of learning, and the rate of forgetting.]

The Learning of Sensible Matter.—The learning of sensible matter differs from that of senseless matter, in that it is accompanied by a great number of associations which are wanting in simple mechanical learning,—save, of course, when artificial mnemonic aids are employed. While senseless syllables are linked by associations only in time and space, the learning of sensible matter involves a mastery not only of matter but also of meaning, the effect of which is to knit simpler into more complex units.

Rational learning allows of the formation of manifold associations, which when acting together materially facilitate the desired revival. It is a fully established principle of psychology that while *a*, which has previously been associated with *b*, may no longer be able to reproduce it, yet when *a* is given along with *x*,—which is also associated with *b*, but in too weak a fashion to revive it unaided,—*b* will be reproduced. This summation effect is of undoubted influence in the recollection of sensible presentations.

We have already pointed out (page 157) that the limiting number of letters and of senseless syllables, which can be immediately reproduced after a single reading, is approximately the same for each. But just as a syllable is viewed by an educated person as a unit, although composed of several different letters, so for the purpose of memory a group of words or a short phrase becomes a unit in virtue of its meaning.

We have also examined data (page 158), showing how the increase in length of a series of senseless syllables influences the number of repetitions needed for immediate memory. The subject of those experiments states that he can learn six stanzas of Byron's *Don Juan* at a sitting in fifty-two repetitions. Each of these stanzas contains about eighty syllables in about thirty-six words, when articles, prepositions, pronouns and similar dependent words are left out of account. But he has experimentally shown (page 158) that thirty-six senseless syllables require fifty-five repetitions; whereas a single stanza of poetry requires about eight repetitions. We have thus some measure of the astonishing saving effected by rational associations in the learning of sensible matter.

The superior retentiveness of rationally learnt material is familiar to every one. The same observer found that, whereas he lost 66·3 per cent. in the case of senseless syllables (page 162), with stanzas of poetry he only lost 50 per cent., in relearning twenty-four hours after the original learning. With longer intervals of time, this difference in retentiveness between rational and merely mechanical learning becomes yet more striking. It has been observed that, even twenty-two years after a piece of poetry has been learnt, a saving of 7 per cent. may be effected.

The Superiority of Rational Learning.—Individuals differ very much in their relative use of mechanical and rational learning. Those who have unusually strong perseverance

tendencies or unusually vivid imagery, are able to depend very largely on the former method, especially for immediate memory. Relying on mechanical learning, a boy will master his lesson successfully by repeating it just before he comes to class, and an actor may become word perfect in his part at a few hours' notice. But folk thus gifted with good immediate memory are apt to retain what they have learnt for a comparatively short time. "Digested" is superior to "crammed" learning for the purposes of mediate memory.

The Influence of Practice and Age on Memory.—We have several pieces of experimental evidence indicating that memory improves with practice, and that at least *immediate* memory improves in children with advancing years. We have, however, yet to determine in what this improvement of memory consists.

If we accept the prevalent view, that an experience leaves its impress on the brain, just as a seal makes its mark on wax, it is open for us to suppose that the depth of such impressions (hence their retentiveness or reproducibility) varies with the practice or age of the individual. Or, believing that the impressionability of brain substance is a fixed unalterable inheritance for any given individual, we may suppose that whatever later improvements in memory occur are due to the play of increasing intelligence and other factors influencing the general attitude of the individual, to some of which we have already drawn attention.

A third course, however, is open to us. We may with good reason dismiss the comparison of the impressionability of the brain with that of wax as improbable; and we may prefer to express the phenomena of memory solely in terms of perseverance tendencies and association strengths. We may then attribute the influence of practice and age on memory to the action of such factors as we have just mentioned upon the perseverance tendencies and association strengths of experiences.

If we are thus inclined to regard the differences in memory, arising from practice and age, as due not to changes in the congenital impressionability of the brain-substance, but principally to differences of mental attitude inseparable from increasing practice and age, we must not overlook the more direct influence of physiological conditions on the perseverance tendency and the association strength of experiences. Drugs, fatigue, and disease may unquestionably affect both these factors. The falling-off of memory in old age is doubtless chiefly due to a general decrease in association strength both for remote and for recent experiences. In old age, associations which once were easily effective become only effective with difficulty, while those which were with difficulty effective now pass altogether below the threshold. In a search for further determining factors, it is important to avoid careless confusion between the various conditions which are commonly involved in memory. For example, the psychological processes which effect the mere "recognition" of an experience are very different from those effecting the voluntary or spontaneous "reproduction" of an experience.

The important influence of what we have called the "general attitude" on learning is indicated by experiments which have been conducted, with the object of determining whether prolonged practice in learning senseless syllables effects improvement in subsequently learning sensible syllables, numbers, passages of prose and poetry, and other kinds of material. It appears that improvement both in speed of learning and in retentiveness occurs for all kinds of learning, but that it is the more marked, the nearer akin be the subsequent material to that on which practice had been bestowed.

Individual Differences of Memory.—Apart from the effects of age and practice, individuals show differences dependent on the interest and intelligence which they bring to their work. Moreover, a strong perseverance

tendency in one individual will rivet his attention to the task, while another, in whom it is weak, will be easily distracted by chance impressions. Again, for various reasons, the mean association strength may differ in any given two individuals.

But even when individuals possess the same mean perseverance tendency and association strength, and learn the same material under the same external conditions, nevertheless their tendency or ability to reproduce that material may not be the same, owing to individual differences in the play of other conditions. For we may assume that ideas are continually struggling among one another to occupy the focus of consciousness, and that there is a constant rivalry between the play of reproduction effects and the ceaseless inflow of sensory impressions. And we may suppose that the suppression of adverse perseverance tendencies and the liability of associations to inhibition vary with different individuals, and indeed with the same individual at different ages.

BIBLIOGRAPHY.

The following are added to the references given in the previous chapter:—A. Jost, "Die Associationsfestigkeit in ihrer Abhängigkeit von d. Vertheilung d. Wiederholungen, *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1897, xiv. 436. L. Steffens, "Experimentelle Beiträge zur Lehre vom ökonomischen Lernen, *ibid.* 1900, xxii. 321. C. Pentschew, "Untersuchungen zur Oekonomie u. Technik d. Lernens," *Arch. f. d. ges. Psychol.*, 1903, i. 417. E. Ebert u. E. Meumann, "Ueber einige Grundfragen d. Psychol. d. Uebungsphänomena im Bereiche d. Gedächtnisses," *ibid.* 1904, iv. 1. W. H. Winch, "Immediate Memory in School Children," *Brit. Journ. of Psychol.*, 1904, i. 127; 1906, ii. 52. "The Transfer of Improvement in Memory in School Children," *ibid.* 1908, ii. 284. P. Ephrussi, "Experimentelle Beiträge zur Lehre vom Gedächtniss," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1904, xxxvii. 56, 161.

CHAPTER XIV

ON MUSCULAR AND MENTAL WORK [1]

The Determination of Efficiency.—The efficiency of an organ is determined by its output of work during unit periods of time. We measure the efficiency of glandular tissue by observing the quality and quantity of its secretion, and by taking into account the conditions under which the secretion has been poured forth. We measure the efficiency of muscular tissue by observing the extent and frequency of its contractions, and by taking into account the conditions under which the tissue has contracted, *e.g.*, the resistance which the force of contraction has had to overcome. Such tissues or organs can be experimentally isolated from the influence of other tissues or organs; we can thus simplify the conditions affecting their activity.

But the efficiency of the nervous system is a more difficult matter of investigation. For, so far as nervous activity manifests itself as consciousness, it must be gauged by the nature and amount of mental work performed. And, so far as it serves unconsciously to co-ordinate or to direct the activities of other tissues of the body, its work cannot be adequately studied apart from its effects on the tissues which it controls.

The Interrelation of Mental and Muscular Activity.—Desirable as it is to base our knowledge of complex activities on a preliminary study of simpler ones, we must not forget that the conditions which obtain within the intact

[1] See footnote to Chapter III.

living organism are very different from those which are artificially induced by the experimental isolation of organs to which we have just referred. We shall presently see that voluntary muscular work is determined not only by local, but also by very remote and by general conditions; for example, that it is closely dependent on the mental condition of the individual at the moment. Similarly, mental activity cannot be isolated from muscular activity; for every idea tends to gain expression in movement, and every state of attention or of emotion is largely dependent on movement. Moreover, the presence of the katabolic products of muscular activity in the general circulation and the central strain involved in any volitional muscular exertion, materially affect the efficiency of other forms of volitional, *e.g.* intellectual, work.

Obviously, then, muscular and mental work are so closely related in the intact organism that it is impossible properly to study the one if we neglect the other. We shall, accordingly, first attempt a brief analysis of the conditions affecting muscular work.

Muscular Work.

Ergography.—The work performed by an active muscle, whether removed from or intact in the body, may be best determined by means of graphic records. The movements of the contractile tissue are communicated to a suitable lever, which accurately registers the height of each contraction. This lever is provided with a writing point, which is brought to bear on a slowly travelling smoked surface. By such means an "ergogram," or graphic record of the work done, may be obtained. The height, number, and frequency of the contractions and the resistance which the contractions overcome can easily be deduced. In experiments on voluntary contraction (exp. 98), the simplest possible movement is usually chosen, *e.g.* regular flexion and extension at

a single finger joint; the weight lifted is sufficiently heavy to tax the subject's efforts nearly to their utmost; the movements of the finger are executed at a prescribed rhythmical rate, and they are graphically registered in the form of an ergogram (fig. 4).

Peripheral and Central Factors in Muscular Fatigue.— The chemical products of muscular activity, as contraction follows contraction, accumulate within the muscle more rapidly than they can be removed by the blood stream or replaced by the reconstruction of material available for fresh work. In the case of the living muscle, isolated, with its motor nerve, from the organism, a state of total muscular exhaustion appears to be safeguarded by the delicate constitution of the end plate. It is believed that this structure, which forms the point of connection between the nerve and the muscle fibre, suffers fatigue earliest. In the intact living body, however, the apparent fatigue produced by volitional muscular exercise seems to have a more central origin. For, when a series of contractions have been volitionally obtained, and when ultimately no further contractions can be volitionally produced, they may nevertheless be evoked by electrical stimulation of the motor nerve.

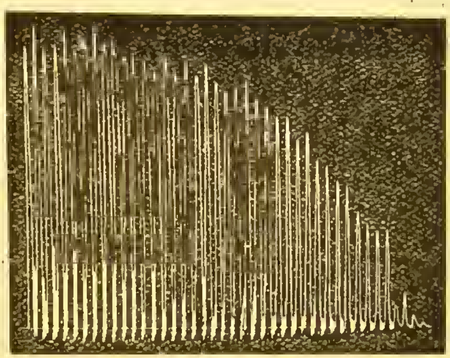

FIG. 4.

It has been suggested that this apparently central fatigue of the intact organism has its seat in the nerve cells of the central nervous system, which saves the delicate end plates from being exhausted, just as the end plates protect the muscle fibre. But this is an improbable explanation. We shall presently see that it is highly improb-

able that the nerve cells of the brain or cord become exhausted during an ergographic record. And we shall bring forward evidence to show that the experience of absolute impotence which marks the close of an ergographic tracing is due, not so much to true protoplasmic fatigue, as to the inhibitory and sensory effects of impulses which ascend to the motor centres of the cortex and cord along the afferent fibres with which every muscle and tendon are supplied. Let us first consider the inhibitory effects, and their importance in muscular activity.

The Inhibitory Effect of Afferent Impulses.—It is well known that the afferent fibres, running from the muscular (and other) tissues of the body to terminate around the cells of the motor nuclei of the cord, bulb, and mid-brain (page 74), play an important part in reflexly co-ordinating muscular action. Experiments have repeatedly proved that, in the absence of these afferent impulses, our bodily movements become seriously hampered and irregular. The important function of these impulses is best seen in the case of limb movements. Here it has been shown that the various motor centres of the cord, which control the movements of flexion and extension, are alternately excited or inhibited, owing to the play upon them of afferent impulses peripherally derived from the movements themselves. The contractions of one (*e.g.* a flexor) group of muscles reflexly inhibit the simultaneous activity of the antagonistic (*e.g.* extensor) group of muscles, the extensor centres of the cord being reflexly inhibited when the antagonistic flexor centres are active, and *vice versâ.*

The Different Effects of Constant and Variable Loads.—The effects produced on muscular work by these afferent impulses seem to be largely dependent on the amount of resistance which the muscular effort has to overcome. Let us suppose that an ergogram, like figure 4, is being obtained by regularly flexing and extending a finger to its maximal extent every two seconds, and that the finger has to raise

a load of five kilograms. After a short time the finger will be in a state of apparently complete exhaustion; no further voluntary movement can be obtained. If the weight of five be now replaced by another of four kilograms, a fresh excellent ergogram can be immediately obtained. Or if the weight be lightened just as the ergograph curve begins to descend, the original maximal height of lifting is once more attained; and by successive reductions of the weight a stage may at length be reached when the height of the rhythmical contractions can be maintained at a constant level for some hours without further change of weight.

The decrements by which the weight is diminished in this method of using a variable load may be plotted out in the form of a curve. Such a line falls rapidly at first, and afterwards more slowly, finally reaching a fairly constant level. Obviously it is of very different form from the outline of an ergogram obtained, as in fig. 4, by using a constant load. But it perhaps gives a truer picture of the course of muscular fatigue. Moreover, it corresponds to the curve yielded when a dynamometer is grasped for a prolonged period (exp. 155), and it corresponds to the curve of work calculated from each of a series of ergograms, when the weight lifted is constant, a sufficient interval of rest being allowed between consecutive ergograms to permit of recovery from the corresponding fatigue effects.

We see, then, that a single ergogram obtained by the use of a constant load records the onset not of general fatigue, but of fatigue towards a special set of circumstances; the condition is one of special rather than of general impotence, and is attributable in part to the inhibitory action of afferent impulses from the motor apparatus. Probably for like reasons, a new series of contractions can be elicited by electrical stimulation of a motor nerve, after the muscle has been apparently tired out by a series of volitional contraction (page 185). When, at length, such a muscle no longer responds to electrical

stimulation, it may once again be thrown into contractions by the will.

Accordingly, we are led to suspect that muscular fatigue in the intact organism bears a close resemblance to muscular practice. Just as a practised muscle, when put to strange uses, may fail to show the beneficial effects of a different previous exercise, so an apparently fatigued muscle may no longer exhibit signs of fatigue when it begins to work under different conditions.

The Sensory Effect of Afferent Impulses.—Let us now briefly consider the same afferent impulses from their *sensory* aspect. When the motor apparatus is anæsthetic, the usual sensations of fatigue are absent, and muscular activity can be abnormally prolonged. Those sensations of fatigue are perhaps partly due to the accumulation of katabolic products within the muscles, for we know that they are most rapidly dissipated by muscular massage. But, at all events, we must always carefully distinguish between the subjective symptoms and the objective signs of fatigue. To feel fatigue is by no means inconsistent with the performance of increased muscular work; the former is never a safe criterion of the latter.

The Influence of Affection and Interest.—Muscular efficiency is affected by any sensory impulses which change the affective state of the organism (page 334). Increased interest or undue mental excitement leads to the performance of an abnormally large quantity of muscular work. On the other hand, the pain which is sometimes met with, owing to the confined position of the moving part in ergographic work, may seriously reduce the output of muscular work.

The Influence of Mental Fatigue.—On physiological grounds we should expect that the presence of fatigue products, whatever their origin, would be detrimental to voluntary muscular work. But an unusually good ergogram may, in many instances at least, be obtained, when the

contractions are preceded by a prolonged period of intellectual work which has undoubtedly involved considerable fatigue.

The Complexity of the Conditions of Muscular Efficiency.—At present we can only record, we cannot satisfactorily account for, these various influences. It may be that certain afferent impulses, which under ordinary conditions are able to limit the efficiency of a previously active muscle, under other conditions no longer discharge this protective function, so that the muscle performs a preternatural amount of work. It may be that undue mental excitement or mental fatigue directly induces a heightened central motor excitability.

But powerless as we are to pronounce definitely on these matters, their mere mention serves to show how complex are the factors influencing voluntary muscular efficiency. We see that the purely muscular system is overruled by higher and still higher series of nervous functions. We see how practice and fatigue in muscular performance within the intact organism are dependent both on mental and on extra-mental factors. We obtain a hint, too, of the nature of the underlying differences, in virtue of which one and the same muscular task is performed in such various ways by different persons.

Mental Work.

Methods of Procedure.—There are, broadly speaking, two methods of measuring mental efficiency. In the one, a period of mental work is interrupted from time to time by a certain psychological test, and the mental efficiency of the subject is estimated by the degree of success with which at different times he performs the interpolated test. In the other method, the subject is confined to a given task throughout the period of investigation, and variations in his mental efficiency are directly deduced from the varying

quality or quantity of his work, performed in like intervals of time at different stages of the investigation.

The Interpolation Method.—The tests which have been used for interpolation in the first method may be classed as "æsthesiometric," "ergographic," and "mental."

The Æsthesiometric Test.—The æsthesiometer, merely a form of Weber's compasses, serves to determine the spatial threshold (page 231). Now, it has been claimed that the smallest distance at which a double touch can be distinguished on the skin serves as a measure of the mental fatigue of the subject. We shall later (Chapter xvii.) draw attention to the psychical factors influencing the spatial threshold; and we may at once concede a general correspondence between mental fatigue and the threshold for the discrimination of two points. But it would be ridiculous to insist that the threshold affords an accurate estimate of the absolute degree of mental fatigue in a given individual, or that it allows of a comparison of the relative degrees of fatigue in different individuals.

The Ergographic Test.—The use of the ergograph for estimating mental fatigue is open even to still more serious objections. We have seen (page 188) that a state of mental fatigue, so far from being detected by muscular inefficiency, is compatible with the production of an unusually good ergogram.

The Combination Test.—The following "mental" tests, that have been employed, involve reading, learning, and calculation (exp. 100).

In the "combination" test an interesting story is read by the subject, in which certain words or parts of words are omitted. The subject has to supply these omissions, and his efficiency is estimated by the amount that he reads, by the correctness of the words he supplies, and by the number of words which he has omitted to supply.

The Letter-erasing Test.—In the "letter-erasing" test the subject is told to read through the pages presented to

him, and to cross out every example of a specified letter. His efficiency is estimated by the amount of matter read, and by the number of occasions on which the specified letter has escaped his notice.

The Learning Test.—In the "learning" test some simple material (a series of letters, figures, or syllables) is presented, which the subject has to commit to memory. His mental efficiency is determined by the number of repetitions which are required before the series has been learnt.

The Calculation Test.—In the "calculation" test the subject has to effect a series of simple additions or multiplications, the number of figures added or multiplied serving as an index of his efficiency.

The Relative Reliability of the Methods.—This first method, which we have been describing, the method of interpolating tests, is for many reasons less satisfactory than the second (or "continuous") method. We cannot legitimately assume that the test measures the impaired efficiency brought about by quite another piece of mental work. The interpolation of a test always involves a change of interest, and thus a disturbing factor, favourable or unfavourable to the test, at once appears on the scene. Moreover, the attitude of the subject towards the test must be widely different at different applications, owing to increasing practice and other causes. In consequence, this method is not so well fitted for an accurate study of the conditions affecting mental efficiency as the second method, in which the subject labours uninterruptedly at a given task, and his power of work is estimated by the amount and accuracy of his output in equal intervals of time.

The Continuous Method.—For the second method any of the mental tests just described are available. Most of the results, however, to which we shall allude have been obtained by use of the calculation method; the subject having to add successive pairs of printed single figures together, and to draw a line at the particular figure reached by him upon

hearing a signal, which is sounded every minute, or every five minutes.

The Mental Work Curve.—By this method we are able to construct a work curve (fig. 5); the divisions on the abscissa denoting successive equal intervals of time, the ordinates giving the amount of work, *i.e.* the number of additions performed during successive intervals. The number of errors in such simple sums is found to be negligibly small.

Fatigue and Practice.—The curve thus obtained at a single sitting may or may not rise at first, but sooner or later it cannot fail to fall owing to increasing fatigue. It is true that along with increasing fatigue goes increasing practice; so far as we know, the two are inseparable. But it is chiefly in the early stages of work, when the gain by practice exceeds the loss by fatigue, that the work curve rises.

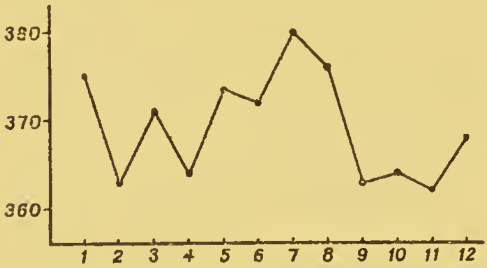

Fig. 5.

The influence of practice is most evident at the early stages of experience. Thus during twenty-six days' exercise at simple addition an average daily gain of 12·2 per cent., due to practice, was obtained during the first ten days, whereas for the next ten days it amounted only to 2·6 per cent., and for the last six days it fell to 1·9 per cent. This decrease in the increment contributed by practice is to be observed when a series of consecutive daily work curves are compared. Owing to the diminishing practice gain in the latter curves, the fatigue effect shows itself sooner than in the earlier curves.

The Factors in Fatigue.—Whereas the practice gain during an uninterrupted task grows less and less, the fatigue increases indefinitely until a limit may be reached

when no further work can be performed. A small part of the fatigue involved in the addition of figures is of muscular origin; the hand tires of its cramped position and of frequent writing. In some experiments this source of fatigue has been eliminated by excusing the worker from writing down his arithmetical results; but such a procedure restricts the experimenter to unusually reliable subjects. Even then the effects of eye strain remain, which, in some individuals at least, contribute not a little to their fatigue. When, instead of the addition test, typewriting or some other form of manual activity (*e.g.* marking the dots already figured on a rapidly unwinding roll of paper) is employed, muscular fatigue becomes still more prominent. With adequate practice, however, it nearly or altogether disappears. Moreover, by increasing the hardness of the mental task, *e.g.* by multiplying series of three, four, or more consecutive single figures "in the head," it is possible to reduce the degree of muscular fatigue and at the same time to enhance the mental fatigue involved.

[From the physiological standpoint there are conceivably two chief sources of mental (as of muscular) fatigue, the one arising locally from the actual wear and tear of the part exercised, the other more widely spread, and resulting from the presence of harmful waste products in the general circulation. The former possible source of fatigue is removable by increased tissue repair, the latter by a better regulated excretion of waste products. At present we are ignorant of any differences that may exist in the psychological expression of these two physiological factors.

Indeed, it is quite likely that one of them, namely, excessive wear of the nervous system, is comparatively unimportant within the limits of normal health, and that its influence is usually safeguarded by other factors. At all events, we must bear in mind the possibility that many of the signs of mental fatigue may be simulated, either through the play of inhibitory nervous impulses,—as in the case of

muscular fatigue (page 186),—or owing to the finally successful competition of rival processes which have previously been held in check to the advantage of the processes exercised. It may be urged that such factors are referable, on the psychological side, to experiences of boredom rather than of true fatigue. But boredom, the weariness produced by monotony of pursuit, is so nearly related to fatigue, the outcome of exhausting mental work, that in the present state of experimental psychology their separation is impossible.]

Spurts.—Were the amount of work, as shown in the mental work curve, solely an expression of the two opposing factors of practice and fatigue, we should expect a far smoother curve than that which we customarily obtain. We have to explain the irregularities, the various peaks and depressions which it contains. These are no doubt the results of distraction, flagging interest and increasing fatigue, which either unconsciously or when brought to the notice of the worker lead to momentary "spurts," *i.e.* to increase in the volitional strain or tension which he brings to bear on his task.

At two periods in the course of the work curve, spurts of a slightly different causation are frequently met with. The one occurs at the very start of a task, when the subject is fresh and brings to his work a marked degree of volitional tension which it is impossible for him to maintain for many minutes. The other occurs when he feels he is nearing the end of his task. The "initial spurt" is experimentally unavoidable, but the "end spurt" may be prevented by irregularly varying the duration of the subject's work from day to day.

A little consideration will convince us that it is this ever variable factor of volitional tension which is chiefly affected by fatigue. We can hardly suppose that the time involved in the sheer mechanical addition or multiplication of two figures materially lengthens as fatigue increases.

It is rather the difficulty of concentrating our attention on the figures, and of realising their meaning, that brings about the diminishing output of our work.

Incitement.—In addition to practice, fatigue, and spurt, a fourth factor is recognisable in any work curve. To this we may give the name "incitement." It occurs at the start of work after a period of previous rest. We may compare our working selves to machines which start with a certain amount of inertia, and require "warming up" before they reveal their true efficiency. The result of the loss of incitement is familiar enough, when we return to a task from which we have been called away, even for a few minutes. What is missing is something quite different from a loss of practice. The human machine has "grown cold" during the interval. The loss in the output of work after such a period of rest is due to the absence of this factor of incitement.

[*Adaptation.*—Between the effects of incitement and "adaptation" it is difficult to draw any fast line. Yet Kräpelin, to whom we are chiefly indebted for this analysis of the work curve, has made endeavours to distinguish them. While the results of the loss of incitement show themselves after even a short rest or at the beginning of each day's task during an investigation consisting of several consecutive days' work, the results of lack of adaptation are to be recognised at the very outset, *i.e.* on the first day of such a protracted investigation or upon the recommencement of work after several days of rest. The process of adaptation consists chiefly in acquiring neglect of distracting impressions which so seriously divert the attention of the inexperienced.]

The Effect of Rest on Work.—The effect of rest upon mental efficiency depends *inter alia* upon the length of the rest. It may be readily studied by comparing the output of work before and after a rest pause. A very brief pause is unfavourable, owing to loss of incitement. A somewhat longer pause becomes favourable, owing to the loss of

fatigue which had been produced by the preceding period of work. But although the work done after a pause may be benefited by the loss of fatigue, it may deteriorate, on the other hand, owing to the loss of practice during the pause.

Obviously, then, the relation between the work done before and after a pause varies with the length of the pause. A pause may be experimentally found of such length that the work done after is equal to the work done before the pause. We may term this the "equilibrial pause." Again, another length of pause may be determined, the work done after which reaches a higher value, in relation to the work done before it, than the work done after any other length of pause. We may term this the "most favourable pause."

[*The Determination of Fatigability.*—The increased output resulting from the most favourable pause has been employed in the following way as a measure of fatigability. The percentage of improvement obtained by the most favourable pause is applied to a like period of work in which, however, no pause whatever has occurred; and the fatigability of the subject is estimated by comparing the calculated with the observed output of work during the second half of the pauseless period. For example, let us suppose that the most favourable pause after a half-hour's addition has resulted in a subsequent half-hour's addition of 2449 figures, that is, in an improvement of 3·1 per cent., compared with the addition of 2376 figures before the pause. This improvement, based as it should be not on a single determination, but on the mean of a number of determinations, is then applied to the work done on the first half-hour of pauseless days, *i.e.* of days on which the worker added uninterruptedly for an hour. Let us suppose that the mean number of additions for the first half-hour of the pauseless days is 2380. Then we should expect an improvement of 3·1 per cent. had the most favourable pause been interpolated; that is, we should expect the second half-hour to yield an

output of nearly 2454 additions. As a matter of fact, the mean value of the output during the second half-hour of the pauseless days turns out to be 2391. The difference between the calculated and the observed values, and the ratio of that difference to the absolute amount of work done, have been used as a measure of the fatigability of the subject.]

[*The Determination of Improvability.*—The improvability of individuals has been measured by comparing the efficiency of the work done during, say, the first half-hour of consecutive days. There appears to be a definite relation between the amount of gain from practice and the degree of the subject's fatigue. As with increasing practice the daily practice gain diminishes, so the fatigue effect diminishes in the daily work curve.]

[*The Determination of Retentiveness of Improvement.*—The loss of practice effects, produced by disuse, is familiar to us all. At first the loss is extremely rapid, later it becomes less and less. Thus, while a pause of one day causes a considerable drop in the number of additions performed, the effect of a pause of six days has been said hardly to differ from that of a pause of four months. Individuals, however, vary in their ability to retain practice effects already acquired.

Attempts have been made to measure the retention of practice by use of the data afforded by the most favourable pause. It is assumed that practically all fatigue has disappeared during the most favourable pause, and that the percentage improvement yielded by it gives a measure of the gain in practice derived from the period of work which immediately *preceded* the pause. That percentage is now applied to the work done *after* the most favourable pause, and the calculated value is compared with the actual value next obtained from the worker after a relatively long period of rest. The difference between the two values has been used as a measure of the loss of practice gain during that period of rest.

For example, a subject who improves by 4·8 per cent. after the most favourable pause, does 2916 additions after that pause. Then, if that improvement represented the practice gain, and if that practice effect were maintained, it is argued that the subject should add 3055 figures (*i.e.* 4·8 per cent. more figures than 2916) on the next occasion. Let us suppose that, twenty-four hours later, the subject works for a half-hour, but only succeeds in adding 2868 figures. Then the difference, namely, 187 figures, represents his daily practice loss. A comparison of the results of different individuals, it is urged, yields a measure of individual differences in the retention of practice.]

[*The Meaning of the Most Favourable Pause.* — In the face of the important assumptions that are involved, and the many complicated factors which are at work, it is scarcely necessary to point out that such calculations can only be accepted with extreme caution. For the length of the most favourable pause has at most an approximate value, varying with the condition of the individual and with the length and nature of the task.

Even in the most favourable pause we cannot assume that all fatigue has been lost. It merely expresses the most advantageous balance obtainable between factors favourable and detrimental to efficiency. Further, the percentage gained after the most favourable pause depends not merely on the amount of the worker's previous fatigue, but also on the speed with which it passes away. Owing to individual differences in the rate of recovery from fatigue, two subjects, in whom equal degrees of practice and fatigue had been produced, may yield very different percentages of improvement after the most favourable pause. Lastly, the neglect of the help and corroboration afforded by introspection, and the procedure of applying calculated to expected results, are obviously fraught with danger when we are concerned with psychical, and not merely with physical data.]

Criticism of Laboratory Work.—It may be urged that

such trivial work as adding pairs of figures, marking dots or crossing out specified letters, bears so little resemblance to the ordinary operations of the mind, that we cannot expect to apply the results thus gained by laboratory experiment to the conditions of daily life. Unquestionably, our work outside the laboratory has not, as a rule, that monotonous simplicity which experiment demands for the purposes of accurate measurement. The mind is not merely a machine, and its efficiency cannot be calculated as if it were an engine, making so many revolutions per minute. We have to take into account the important work involved in the guiding, directive activity of the mind. In ordinary life a great part of our mental activity is occupied not so much in directly producing work as in elaborating and satisfying a procession of ends. We are always forming and realising ends, which in turn are not final but are a means to greater ends, and so on. Mental activity is therefore analogous not merely to the wear and tear of a machine, but also to the directive agency of the engineer.

Compared with its importance in everyday life, this factor of directive agency plays an insignificant part in the laboratory task of marking dots or of adding pairs of figures. We have only to practise an hour's such addition work, say for ten consecutive days, to discover how automatically the work comes to be carried out, despite every effort to prevent automaticity. The same holds to a surprising degree even with much harder tasks, *e.g.* multiplying series of three figures "in the head." Our thoughts insist on wandering into other channels, while the dull task of adding or multiplying proceeds quite happily without appreciable help from consciousness. From time to time we recall ourselves to the task,—whether always to the improvement of the latter being uncertain.

To this objection we can only reply that experiment must necessarily start from the simplest conditions, and that just as the other abstract sciences, when at length they

are employed in applied science, approach more and more closely to the concrete of ordinary experience, so psychology, once having gained the necessary knowledge under simpler conditions of experiment, may some day be enabled to devise experiments more complex and more analogous to the conditions of workaday life.

BIBLIOGRAPHY.

A. Oehrn, "Experimentelle Studien zur Individualpsychologie," *Psychol. Arbeiten*, 1896, i. 92. E. Amberg, "Ueber d. Einfluss d. Arbeitspansen auf d. geistige Leistungsfähigkeit," *ibid.*, 300. W. H. R. Rivers and E. Kräpelin, "Ueber Ermüdung u. Erholung," *ibid.*, 627. H. Ebbinghaus, "Ueber eine neue Methode zur Prüfung geistiger Fähigkeiten, u. ihre Anwendung bei Schulkindern," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1897, xiii. 401. A. Binet et V. Henri, *La Fatigue Intellectuelle*, Paris, 1898. E. H. Lindley, "Ueber Arbeit u. Ruhe," *Psychol. Arbeiten*, 1900, iii. 482. J. Joteyko, "Participation des centres nerveux dans les phénomènes de fatigue musculaire," *L'Année psychol.*, 7me année, 1901, 161. Z. Treves, "Ueber die Gesetze d. willkürlichen Muskelarbeit, *Arch. f. d. ges. Physiol.*, 1910, lviii. ; "Le Travail, la Fatigue et l'Effort," *L'Année psychol.*, 1906, 12me année, 34. E. Kräpelin, "Die Arbeitscurve," *Philosoph. Stud.*, 1902, xix. 459. A. Mosso, *Fatigue*, Eng. trans., London, 1904. W. H. R. Rivers, *The Influence of Alcohol and other Drugs on Fatigue*, London, 1908.

CHAPTER XV

ON THE PSYCHO-PHYSICAL METHODS[1]

The Uses of the Methods.—The principal object of these methods is to determine the conditions of our experiences of equality and difference. This forms a most important theme of research in experimental psychology. [For experiences of equality and difference underlie (i.) the determination of the "differential threshold," in which the smallest appreciable difference, produced by two different stimuli, is ascertained.

The same experiences are in great measure involved in (ii.) the determination of the "absolute threshold" of an experience (the presentation, for example, being one of minimal intensity or quality, or one of minimal temporal or spatial extent); for here, as we shall subsequently see, the subject's attitude is essentially one of discrimination between the just appreciable and the inappreciable.

Experiences of equality and difference are also involved in determining the conditions of apparent equality between two experiences. Apparent equality may relate simply to (iii.) the experiences of two objects; as for example in the determination of equality in the lengths of two lines or in the brightnesses of two lights.

On the other hand, it may relate to (iv.) the experience of the differences between two pairs of objects; as for instance when we determine that the difference between the loudnesses *a* and *b* of one pair of sounds is equal to the

[1] See footnote to Chapter III.

difference between the loudnesses *b* and *c* (or *c* and *d*) of another pair of sounds.

In none of these four lines of research can we strictly be said to measure subjective experiences of equality or difference. We can only measure the objective intensities (or extents) of stimuli which produce those experiences. Hence, speaking in terms of physical stimuli, in place of psychic experience, we may say that these four lines of research respectively involve the determination of (i.) the differential threshold of the stimulus, (ii.) the absolute threshold of the stimulus, (iii.) the apparent equality of stimuli, and (iv.) the apparent equality of stimulus differences.

For the investigation of these four problems three so-called "psycho-physical" methods have been devised, intimate familiarity with which is essential for reliable experiment. They are "the method of mean error," "the limiting method," and "the constant method."]

The Method of Mean Error.

This method, sometimes called "the method of production," is especially useful in determining the conditions of equality between two experiences. Taking a simple case, let us suppose that we have to deal with two visual stimuli, each of which consists of a horizontal straight line, one having to be made equal to the other (exp. 101). These lines might conceivably be exposed to the subject, either simultaneously or successively, either instantaneously or for a relatively long period. Let us suppose that they are exposed simultaneously for a prolonged period, and that one of them, which we shall call the "standard" line, lies at the same horizontal level as the other line which is the "variable." The subject is directed (by aid of some simple contrivance) to change the length of the variable line until it appears to him equal to the standard line.

The Crude Constant and Crude Average Errors.—If a series of such determinations of equality be made by the subject and recorded by the experimenter, the difference between the mean of these determinations and the length of the standard gives the mean error of estimation. This is known as the "crude constant error," e_c. Its reliability depends on the deviation of the individual determinations from one another; this can be measured by the mean variation or mean variable error (page 124). The "crude average error" is calculated by finding the mean of the deviations of the individual determinations from the standard, regardless of algebraic sign.

These data, however, would give us no knowledge of the various factors which contribute to the error of estimation. We must not be content with the blurred result arising from such an unpsychological mode of procedure. We must endeavour to analyse the factors and to refine our methods of experiment, so that under certain conditions the influence of one factor, under other conditions the influence of another factor, may be brought to light and specially investigated.

Thus, in the above simple experiment, the subject was presented with a variable line which he had to make equal to the standard line. But, we may well ask, is the result independent of whether the variable line, when presented to the subject, were shorter or longer than the standard line with which it had to be equated? This question can only be answered by making one set of observations in which the subject has to lengthen the variable line, and another set in which he has to shorten it.

The Space and Time Errors.—Moreover, in the above experiment we have not specified on which side the variable lies with regard to the standard line. Consequently, we have also to determine the constant error for a series of observations in which the former line lies to the right and for another series in which it lies to the left of the latter.

Further, we have neglected the influence of the length of the standard and the distance between the two lines.

To analyse and to estimate these various factors is the special province of experimental psychology. In so doing, care must be taken that practice, fatigue, and interest have the same play in differently planned investigations; and we must assure ourselves that the differences, met with under intentionally altered experimental conditions, are significant and not accidental (page 125).

We shall proceed on the supposition that these sources of danger have been avoided. Let us now turn to a consideration of the two constant errors resulting from the position of the variable to the right or to the left of the standard line. If e_1 denote the former, and e_2 the latter constant error, we might expect that the two errors would be equal. As a matter of fact they are usually unequal. If we suppose that these two errors (*i.e.* the errors due to the rightward or leftward position of the variable relatively to the standard) are of equal and opposite value, and if $\pm q$ denote this "space error,"[1] then there is in addition an unknown factor k, influencing the subject's determination. That is to say, $e_1 = k + q$; $e_2 = k - q$. From these two simultaneous equations the values of k and q may be easily found in terms of e_1 and e_2.

The "time error," due to the relative temporal positions of the standard and variable stimuli, has no existence in the method of mean error; for here the standard never follows, but always precedes or accompanies the variable stimulus.

The other factors, to which we have drawn attention, may be successively investigated in like manner; until ultimately, by the aid of introspection which is afforded by the subject, and by changes in experimental conditions which are planned by the observer, all the psychologically

[1] It is usual to give a positive or negative value to the space error, as the left-hand object appears greater or less than the right-hand.

important influences, affecting the constant error, have been analysed and estimated.

The Limiting Method.

This method, often called the "method of just perceptible difference" or "the method of minimal changes," has a wider range of utility than the preceding. In this method the values of the variable, instead of being changed by the subject, are fixed and prescribed by the experimenter.

Its Simplest Form.—The subject begins with a standard stimulus, S, and a variable stimulus, V, which is sufficiently different from the standard as to be obviously greater. The experimenter then plies the subject with successively diminishing values of the variable (*e.g.* $V-\delta$, $V-2\delta$, $V-3\delta$, $V-4\delta$), each given in conjunction with the standard, until finally the subject judges that a certain variable (*e.g.* $V-x\delta$) and the standard are equal.

A series of variables, thus graded, each presented once in regular descending order with the same standard, constitutes a single series of observations. A further series must now be obtained by reversing the order, the subject starting with a variable which is so slightly in excess of the standard that they appear to him equal to one another, the experimenter regularly increasing the variable in successive pairs of presentations, until the subject at length judges that the variable is greater than the standard.

When no standard presentation is used, the limiting method becomes applicable to the determination of the absolute threshold. For such purpose, of course, procedure is only available by descent from the value of the easily appreciable stimulus or by ascent from the value of the unappreciable stimulus.

The size of δ must be appropriate to the conditions of the experiment. If it be too large, the answers become too easy; if it be too small, they become too difficult. In

either case the subject's interest and attention are liable to flag.

The upper differential threshold or limen obviously lies between the last (or first—according to direction) value of the variable, which just allows of a correct judgment of difference, and the first (or last) value of the variable, which just produces a judgment of equality; and we may assume that it lies midway between the two. The difference between the mean value of the variable, thus derived from a number of such series of observations, and the value of the standard gives the upper differential threshold, D^u. The value of the mean variation of the various individual readings expresses the reliability of the result.

We may similarly determine the value of the lower differential threshold, D^l. First we start with a variable V_1, which is obviously smaller than the standard,[1] adding to its increments δ, 2δ, 3δ . . . , until the variable and the standard appear equal to the subject; and then we proceed in reverse order from apparent equality to inequality of the presentations. The values D^u and D^l will slightly differ from one another, owing to the operation of Weber's law.

[*Procedure by Complete Descent and Ascent.*—A modification of the limiting method enables us to determine D^u and D^l in the same investigation. Starting with a variable V which is obviously greater than the standard S, we may reduce it until V is apparently just equal to S, and reduce it still further until V is just less than S. Then we may increase V by successive stages until it appears to be just greater than S. This modification, known as the "procedure by complete descent and ascent," gives us eight values of V. Four are obtained during the descent, namely, (α) that V which is for the last time greater than

[1] V_1 should be as much below, as V was above the threshold; due allowance being made for differences due to the operation of Weber's law.

S, (β) that V which is for the first time not greater than S, (γ) that V which is for the last time not less than S, and (δ) that V which is for the first time less than S; and four corresponding values (δ_1, γ_1, β_1, α_1) are successively obtained during the ascent.]

The Effects of Adaptation and Expectation.—The value of the upper differential threshold obtained by diminishing the variable is usually lower than that obtained by increasing it. Similarly, the value of the lower differential threshold is usually lower when the variable is increased than when it is lowered. We should naturally expect this to result from the subject's preceding experience. It is also in part due to a kind of adaptation, the subject inertly tending to continue to give the same kind of replies as those which he has already given for the immediately previous pairs of presentations.

This tendency, however, may be more or less outweighed by the effect of expectation. In procedure by regular descent or ascent, the subject cannot fail to be influenced by the knowledge that sooner or later the tenor of his answers must change, that at some point his judgments, which for example have hitherto been judgments of excess, must change into those of equality. On the other hand, upon certain individuals the effect of such expectation may be diametrically the opposite. They may so far strive to prevent their anticipatory attitude from influencing the turning-point, that thereby the latter may even be postponed.

Other Modifications of the Method.—Such complications, unless avoided, seriously affect the utility of the limiting method. We have, therefore, to consider the various devices whereby the degree of the subject's foreknowledge may be reduced as far as possible. [In the first place, the time order or space order may be irregularly varied. That is to say, in any single series of observations, sometimes the standard may be presented before, or to the right, or after or

to the left of the accompanying variable. Again, different grades of the variable—$V-\epsilon$, $V-2\epsilon$, etc., instead of $V-\delta$, $V-2\delta$—may be occasionally used in different series of observations. Or, thirdly, the descent (or ascent) may be begun from different variables, say from $V\pm\delta$ or from $V\pm 3\delta$ instead of from V, in occasional series. These modifications must, however, be used with caution; otherwise the remedies bring with them complications greater than those which they are intended to remove. Thus the four time and space orders, in which the variable and standard are presented, must be carefully planned so that they occur with equal frequency in any single series; the number and size of the grades of the variable must be the same in corresponding ascending and descending series; and the number of series, in which unusually few and unusually many grades of the variable are employed, must be so nearly equal that their opposite effects on the average of the total series may countcract one another.

When several series of observations have been made with one time or space order, and other series with the opposite time or space order, the time or space error may be easily deduced by treating the respective threshold values in precisely the same manner as the constant errors were treated in the method of mean error.]

Various other modifications of the limiting method have been devised to ensure unprejudiced replies on the part of the subject. In one modification, procedure by descent and procedure by ascent are combined so that successive pairs of stimuli, within each single series of observations, alternately belong to one or other of the two procedures. The subject's answers can be subsequently sorted out and treated as if they had been given in two separate series, one of descent and the other of ascent. In another modification, the series of variable stimuli are presented, each with the standard in irregular order, each pair occurring once in every series of observations. Here, again, the data may be appropriately

sifted and the upper and lower thresholds subsequently calculated.

Another device, in order to obtain greater freedom from prejudice on the part of the subject, consists in the occasional presentation of a variable which is actually equal to the accompanying standard. But the interpolation of such "catches" has an undoubted effect on the general mental attitude of the observer, and it is difficult to ensure that this disturbing effect shall be constant in successive series of observation. The threshold has been actually found to vary with the number of catch experiments introduced.

The Method of Serial Groups.—A modification of the limiting method may be employed, in which this objection to the irregular use of "catches" does not apply. It has been called the "method of serial groups" (exp. 103). A given value of the variable, V, is presented with a standard, not once as in the limiting method, but several (say ten) times before it is changed to another value. These ten pairs of stimuli are given in irregular order with (say ten) other pairs of stimuli in which the variable is equal to the standard. The twenty pairs constitute a group. If the subject acquits himself, satisfactorily in one group, he passes to a second group of twenty pairs, in which the value of the variable, now reduced to $V-\delta$, again remains constant, and in which ten catch experiments are as before included. Then the experimenter passes to a third group, in which the variable is by a like amount further reduced to $V-2\delta$. For every group the relative number of correct replies is recorded. The threshold in this method is arbitrarily fixed. It corresponds to that variable which yields eighty per cent. of right answers. A similar procedure by ascent follows that by descent. The subject is previously warned that every group will contain catch experiments irregularly distributed. In calculating the threshold, the results of the catch experiments are neglected; but they are otherwise of great interest, psychologically.

The Constant Method.

The constant method is often known as the "method of right and wrong cases." In this, as in the limiting method, the values of the variable are prescribed by the experimenter. But the number of grades of variables is usually much less; they need not form a regular series (although it is more convenient that they should); the order of presentation is irregular; and any given variable is presented not once but many times with the standard in single series of observations. The percentage of right and wrong answers is calculated for each value of the variable, and from them an attempt is made to arrive at the limen or threshold (exp. 102). The threshold is deduced from that value of the stimulus or of the stimulus difference, which in a long series of trials turns out to be as often appreciable as inappreciable.

Thus, in determining the spatial threshold, the following percentages of answers may be cited.[1] The answers are judgments that two points are touching the skin, when it is simultaneously touched by two points at various distances apart. The distances are expressed in Paris lines (=2·25 mm.).

Distance of points	0	0·5	1	1·5	2	3	4	5	6
Percentage of "two point" answers	30	10	14	40	65	80	87	96	100

Clearly the true threshold, D, is at that distance which gives an equal number (50 per cent.) of right and wrong answers. In the above investigation its value lies between 1·5 and 2 lines. Now, if $D\alpha$ be the distance at which α per cent. of correct answers is obtained, and $D\beta$ be the distance at which β per cent. of correct answers is obtained, and if

[1] These data were published by A. Riecker (*Ztschr. f. Biol.*, 1874, x. 190), and are here modified for purposes of exposition according to Titchener (*Experimental Psychology*, New York, 1905, ii. pt. 1, pp. 92, 93, and pt. 2, p. 250).

the value of D lies above $D\alpha$ and below $D\beta$, it can be roughly determined, by the formula

$$D = \frac{D\alpha\ (\beta - 50) + D\beta\ (50 - \alpha)}{\beta - \alpha},$$

to have the value of 1·7 lines.

This value, however, is for many reasons only approximate. In the first place, the formula assumes that the percentage of correct judgments increases proportionately with increase of the distance between the two points. But this assumption is untrue; the percentage increases more rapidly with increase from small to larger distances than from larger to still larger distances.

In the second place, we neglect the necessarily different values of D which result from other values of $D\alpha$ and $D\beta$ and other values of α and β. Clearly, the above experiment might have been so planned that we had no record of the percentage of right answers for the distance of 2 Paris lines between the two points. We should in that case have inferred that the spatial threshold lay somewhere between 1·5 lines, giving 40 per cent., and 3 lines, giving 80 per cent. of right answers. Applying the above formula, the value of the threshold now becomes 1·875 lines instead of 1·7 as before. We have therefore to take into consideration not a single pair but all the different values obtained, paying due weight to the number of experiments that have afforded these several values, and to the degree of scatter of the various thresholds from which the mean threshold is derived. These conditions can be satisfied by the use of complicated formulæ, deduced from Gauss's law of error (page 125), which lie beyond the scope of an elementary treatise.[1]

The threshold may be roughly determined by drawing a frequency curve (fig. 6), the ordinates representing the

[1] A mode of employing the constant method without recourse to Gauss's formulæ has been recently suggested by Spearman (*op. cit.*), to which the more advanced student may be referred.

various observed percentages of right answers, the abscissæ representing (in the example we are considering) the distances upon the skin at which those percentages are respectively given. The value of the abscissa at the ordinate value of 50 may be then determined by graphic measurement, after smoothing, so far as possible, the irregularities of the curve.

[*Reversals.*—We have hitherto assumed that the percentages of right answers, returned at the various distances between the two points, are thoroughly trustworthy. But a glance at the curve, which we have drawn, shows us that we must take into account certain so-called "reversals" of percentage values. We should expect the percentage of right answers to increase more rapidly for the earlier (smaller) than for the latter (larger) distances. For example, we should expect the difference between the percentages of right answers returned for the distances 1 and 1·5 lines to be greater than for the distances 1·5 and 2 lines; and so it is. But this relation is reversed in the case of the percentages for 3, 4, and 5 lines, and again for 0·5, 1, and 1·5 lines. In each of these cases the increase of correct answers is less from the first to second than it is from the second to third of these distances. They are instances of what has been called "reversal of the second order."

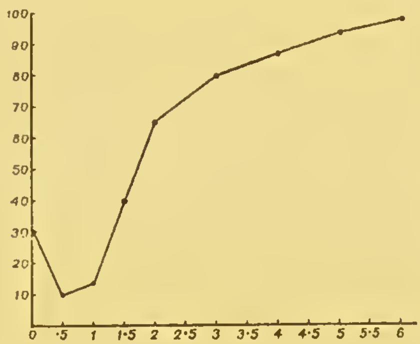

FIG. 6.

It is not uncommon even to find a "reversal of the first order." That is to say, an increase of the distance between the two points, so far from producing an absolute increase, produces an absolute decrease in the percentage of right answers. In a sense, we have an example of such a reversal in the present series, for the percentage of correct judgments

is less when the points are separated by 0·5 lines than when they are not separated at all, *i.e.* when only one point is presented.

An obvious safeguard against these reversals consists in increasing the number of observations and of series of observations. But beyond certain limits this becomes impracticable. Moreover, the influence of practice and fatigue may make the initial and terminal results incomparable.]

So far, for simplicity's sake, we have been considering the constant method in its application to conditions where merely one variable stimulus is employed. But the same method has been still more widely used in recording the judgments between pairs of stimuli (exp. 102), or between pairs of stimulus differences (exp. 122). It has been employed, too, with most valuable results, in order to determine the effect of prescribed conditions on the proportion of right and wrong answers (exp. 121).

Contrast Effect.—In all these applications of the constant method, an important cause of the reversals, to which we have just been alluding, lies in the play of contrast effects. As the various pairs of variable and standard are presented in irregular order, it must often happen (unless the experimenter takes special precautions to avoid it) that the presentation of a large difference immediately follows or is immediately followed by the presentation of a small difference to the subject. Such juxtaposition of extremes cannot fail unconsciously to produce a contrast effect. The difference between a pair of stimuli, which the subject could correctly distinguish under ordinary circumstances, may no longer be detected, if it be immediately preceded by one or more larger and very obvious differences.

Side Comparisons.—Moreover, the answers may at any time be influenced by conscious comparison of one member of a pair with a member of a preceding pair of stimuli. The existence of these "side comparisons" is almost

invariably revealed by adequate introspection during such an investigation.

"Doubtful" and "Equal" Answers.—In describing the constant method, we have hitherto assumed that the stimulus difference is judged by the subject to lie unquestionably either in one direction or in the other; that is to say, we have assumed that the answers can easily be classified as simply right or wrong. This, however, rarely occurs in actual experiment. For, in the first place, the subject is at any time liable to return the answer "doubtful,"—though along with increasing practice the number of "doubtful" answers very much diminishes. And, in the second place, the subject will often return the answer "equal."

The question arises, How are we to deal with these "doubtful" and "equal" answers? Although to some extent they differ from one another, that difference is far less than their difference from the "greater" or "smaller" answers. Obviously, their place is somewhere intermediate between the two last.

Some psychologists have neglected these "equal" and "doubtful" answers altogether in evaluating their results, some have forbidden the subject ever to return them, while others have divided their number equally, adding half to the right and half to the wrong answers. The first procedure is obviously unscientific; the second invites the subject to abandon his desirable attitude of conscientiousness; the third seems the only justifiable procedure under the circumstances.

When the "equal" (and "doubtful") answers are frequent enough to allow of their being grouped together and separated from the "greater" answers on the one hand, and from the "smaller" answers on the other, we can determine by several methods the average value of the magnitude of the variable which, when presented with the constant, gives the greatest percentage of equal answers. Thus, if in a full series of experiments stimulus A is found to give a "equal"

answers, and if stimuli B, C, D, etc., similarly give b, c, d, etc., "equal" answers, then the mean value of the required variable can be deduced from the expression

$$\frac{a\,\mathrm{A}+b\,\mathrm{B}+c\,\mathrm{C}+d\,\mathrm{D}+\ldots}{a+b+c+d+\ldots}$$

Or we may use an alternative method which has been described as a combination of the limiting and constant methods. If a in a series be the smallest value of the variable stimulus which produces the answer "greater" and b be its greatest value which does not produce the answer "greater," and if c be the smallest value which does not produce the answer "smaller" and d be the greatest value which does not produce the answer "smaller," then a mean can be derived from the expression

$$\frac{a+b+c+d}{2}.$$

Other methods besides these two here mentioned are available. But into these and into a discussion of their comparative utility and reliability we cannot enter here.

Method of Equal-appearing Intervals.—The method of mean error, the limiting and the constant methods may be also used to determine the conditions of equality (or of just appreciable difference) between two experiences, which, instead of relating to two stimuli a and b, relate to two differences between the pairs of stimuli a and b, c and d (page 201). When thus applied, the psychological procedure sometimes receives a special name. It is known as the "method of equal-appearing intervals," or the "method of mean gradations." The latter expression, however, is limited to the case of three presentations, a, b, c, where b has to be found which appears to be intermediate in value between a and c. It is strictly inapplicable to the case when that difference between c and a variable d has to be found, which appears equal to the difference between a and b.

In point of fact, there is no single method of equal-appearing intervals. It is merely a special instance of the

application of the method of mean error, the limiting method or the constant method to a particular problem.

The Attitude of the Subject.—Lastly, we have to consider the attitude of the subject in these methods of experiment. He may be allowed to give his replies with "full information," with "partial information," or "without information," according to the purpose of the investigation. Thus he may approach the experiment without knowledge either of the direction of the difference between the stimuli or of the space order or time order which the experimenter is employing. On the other hand, he may for special reasons be allowed the foreknowledge that the standard is smaller or larger than the variable, or that it lies to the right or left of, or is presented to him before or after, the variable. Or he may proceed with partial information, the actual condition of the presentation being told him after each answer. A comparison of the different results thus obtained is of considerable psychological interest.

According to the purpose of the experiment, the subject may be required to give his answers always in terms (i.) of the first or of the second stimulus or pair of stimuli, (ii.) of the right-hand or of the left-hand stimulus or pair of stimuli, or (iii.) of the variable or of the standard. On the other hand, (iv.) he may be left absolutely free to express himself as he pleases, *e.g.* after successively lifting a pair of weights, he may say "right-hand weight heavier," or "second weight lighter," and so on. As we shall see (page 271), such liberty of behaviour throws light on the mental attitude involved in any particular judgment.

The possibly disturbing effects of making introspective records during experiments have also to be reckoned with. That is to say, series of observations with introspection should be compared with those unaccompanied by introspection.

Correspondence between Results of Limiting and Constant Methods.—The play of complicating psychological factors is,

as we have seen, so different in the three psycho-physical methods that *a priori* we should not expect an exact correspondence in the results to which they lead. The method of mean error, in which the subject is free to alter the variable presentation, is obviously incomparable with the limiting and constant methods, in which the value of the variable is each time prescribed by the experimenter. The two last methods, however, may be made to approach one another, if that form of the limiting method is employed, in which the variables are plied haphazard instead of in orderly descent or ascent.

BIBLIOGRAPHY.

G. T. Fechner, *Elemente d. Psychophysik*, Leipzig, 1860; *Revision d. Hauptpunkte d. Psychophysik*, Leipzig, 1882. G. E. Müller, "Die Gesichtspunkte u. d. Tatsachen d. psychophys. Methoden," in Asher and Spiro's *Ergebnisse d. Physiol.*, Wiesbaden, 1903, ii. Abth. 2, 267 (also published separately). E. B. Holt, "The Classification of Psychophysic Methods," *Psychol. Rev.*, 1904, xi. 343. E. B. Titchener, *Experimental Psychology*, New York, 1905, ii. parts 1, 2. C. Spearman, "The Method of 'Right and Wrong Cases' ('Constant Stimuli') without Gauss's Formulæ," *Brit. Journ. of Psychol.*, 1908, ii. 227.

CHAPTER XVI

ON WEIGHT

The Effects of Tactual and Motor Anæsthesia.—We have already observed (page 68) that an individual, deprived of the normal tactual and motor sensations in any part of his body, is unable to move the part with accustomed certainty and precision, or to appreciate the position of the part or the event of its active or passive movement, when his eyes are closed. He believes that he has moved the part, when it has been so held as to be immovable. He believes that the part is stationary, when it has really moved.

Conjoined with these defects is the inability to estimate weight. When a limb is totally anæsthetic, heavy and light objects of like outward appearance appear of equal weight. So long as motor sensation is intact, the power of estimating the weight of lifted objects is preserved. It is retained, even when the skin has been rendered anæsthetic.

Behaviour in Estimating Weight.—In judging the weight of objects merely by their contact with our body (as when an object presses upon the unsupported hand), our estimate is based partly, perhaps, on the cutaneous sensations, but principally on the motor sensations of deep pressure and tension which the object evokes. Under such conditions, our judgments of weight are very largely influenced by the rate of application of the object to our body.

In ordinary life, however, we are in the habit of estimating the weight of objects by raising or lowering them, or by raising *and* lowering them. To our experiences of tension and of

pressure we thereby add those of movement. We are able to note the speed with which and the height to which the object rises, and the time that elapses between the determination to lift the object and its actual ascent. All these factors are of the greatest importance in influencing our estimate of weight.

Influence of the Speed of Lifting Weights.—The influence of the speed with which lifted objects rise from the ground, on our judgment of their weight is open to experimental investigation. An electric circuit, connected with a chronoscope (see exp. 88), is so arranged that the current is interrupted directly the object leaves the ground, and is restored when the object, during its ascent, makes a second contact at a known height from the ground. Experiments, conducted on these lines, have shown the great importance of the rate of movement upon our estimation of the weight of a lifted object. Other things being equal, the more rapidly a lifted object ascends, the lighter it appears to be.

This influence of the rate of movement persists, when the eyes are closed and when the skin has been rendered anæsthetic. It disappears in the case of patients suffering from locomotor ataxia, a disease in which motor sensation is much impaired. Its dependence upon the sensations of the motor apparatus is, therefore, unquestionable.

When two objects are simultaneously lifted, one by each hand, our comparison of their weights appears to be affected by the difference in the time taken to set each of the objects in motion. If two objects of actually equal weight be lifted with apparently equal expenditure of force, and if one object begin to rise before the other, it seems that that object tends to be judged the lighter.

Tactual and Visual Influences.—In proceeding to lift an object, we are also guided by our tactual or visual perception of it. Experience has taught us that, when a large object presses on the skin, or when a large object is grasped or seen,

the amount of muscular effort, requisite to lift it, is greater than in the case of a smaller object.

The Size-Weight Illusion. — Consequently, when two objects of unlike size and of equal weight are lifted, the fact that they are felt or seen to be of unlike size irresistibly determines a difference in the strength of muscular contraction put forth in order to lift each of them. The larger object rises more rapidly than the smaller one and is for this reason judged to be the lighter of the two, whereas the weight of the two objects is actually the same. This cause of error is commonly called the "size-weight illusion." By reason of it, a pound of feathers appears lighter than a pound of lead (exp. 102).

The size-weight illusion may be investigated and measured under various conditions. Thus the subject may be permitted both to see the weights and to grasp them; or he may be required to grasp them blindfold; or with open eyes he may be allowed to raise the weights by grasping handles of equal size attached to them. The illusion is present in all three cases, but is strongest in the first, where prehensile and visual influences are conjoined. It varies widely in different individuals, and is, as we might expect, more marked in adults than in children. Indeed, in very young children, the apparent difference in weight of the two objects is said to be absent, or even reversed, the larger object then appearing the heavier.

We have described the difference in our mode of lifting the objects in the size-weight illusion as irresistible. That is to say, it persists, in some considerable degree, even after we have been made aware of the illusion. We can therefore hardly ascribe the illusion to "suggestion," in the ordinary sense of the word. "Unconscious inference" would be a better term. The amount of muscular effort, put forth in lifting an object, is unconsciously inferred from and irresistibly determined by its size.

Even when two objects are of like size and weight, the

fact that the one is seen to be of light and the other of heavy material influences the amount of muscular contraction put forth. For this reason a solid cube of wood appears to be heavier than a hollow leaden cube of like size and weight.

Motor Attunement.—We have now to discuss another condition which unconsciously influences the amount of muscular effort put forth,—a condition which we may term "motor attunement." Experiments have shown that, if two objects of equal size but of different weight (*e.g.* two like canisters weighing 676 and 2476 grams) be alternately lifted, say thirty times, the lighter say by the right hand and then the heavier by the left hand, with equal speed and to an equal height, a state of motor attunement is ultimately established. In this condition, an object lifted by the left hand appears lighter than an equal or even lighter object then lifted by the right hand. Thus, when in the above experiment one or other of a series of weights, varying from 826 to 926 grams, is substituted for the heavier of the two weights, it is judged by the subject to be lighter than the really lighter weight of 676 grams.

Evidently we have at hand a ready explanation of this error of judgment, if the effect of repeatedly lifting a lighter, followed by a much heavier, object is to establish an attunement or "set" of the system, which manifests itself in a tendency to lift the second of any subsequent pair of weights with a greater expenditure of force than is given to the first. That second weight, if it be no longer much heavier than the first, must rise with greater speed than the first and accordingly appear the lighter. We have undoubted evidence that this more rapid rise of the second lifted weight actually occurs, and that it is the cause of the erroneous judgment.

When attunement has been in this way established, our judgment may, at the same time, be influenced in the opposite direction by the more intense sensations of pressure and tension which the second, actually heavier, weight

evokes; or our judgment may be embarrassed owing to the unexpected rapidity with which this weight rises. There are, therefore, tendencies at work either to mitigate the error or to increase the uncertainty of our judgment.

In the above-mentioned experiment, attunement is effected by alternately raising two weights, one in either hand. It may likewise be effected when the two weights are consecutively lifted by the same hand, or when a series of lifts of light weights precedes the lifting of a heavy weight. In the above experiment, too, the order in which the weights are lifted is "light, heavy." That is to say, first a light weight is lifted, and then a heavy weight is lifted; whereupon the subject is asked to compare the weights. Attunement can also be effected in the reverse direction, namely, "heavy, light." It is, however, usually less marked and may even be reversed, owing to some counteracting influence of the time error (page 204).

A motor attunement, thus acquired, disappears in course of time, at first rapidly, later more slowly. In certain experiments, traces, more or less evident, of such a motor attunement have been found even twenty-four hours after its acquisition.

The Possibility of Transference of Motor Attunement.—The following will serve to exemplify an investigation, designed to determine whether motor attunement, acquired on one side of the body, has any effect upon the corresponding movements of the opposite side. A series of pairs of weights (of like size and appearance) are lifted consecutively by one hand. One of the members of each pair is a constant weight of 500 grams; the other is a variable weight of 450, 500, 550, 600, 650, or 700 grams. The constant weight always lies to the right of the variable, and is always lifted first. The two weights are raised and lowered through an equal distance. A metronome, beating eighty-four strokes to the minute, fixes a constant speed of lifting. The first weight of a pair is raised at the first stroke of the metronome

and is lowered at the second; the second weight is raised at the third stroke of the metronome and is lowered at the fourth. The subject's judgment as to the difference or equality in the two weights is then recorded. Eighteen lifts of the six pairs, presented in carefully designed order, constitute what we may term the "pre-attunement experiments." After a pause of two minutes, they are followed by the "attunement experiments"; in which a series of sixty pairs of lifts is made, the pairs being a weight of 500 grams lying to the right and lifted first, and a weight of 2260 grams (of course, of like size) lying to the left and lifted second. These sixty pairs are divided into six groups, each group being separated by an interval of forty-five seconds from the other.

Finally, after another pause of two minutes, come the "post-attunement experiments," which are an exact repetition of the pre-attunement experiments, and are to be compared with them.

These eighteen pairs of lifts in the pre- and in the post-attunement experiments, together with the sixty pairs of lifts in the attunement experiments, constitute one day's research. The whole investigation lasts twenty days, which are divided into five four-day groups. On the first day of each four-day group, the pre-attunement, the "habituation," and the post-attunement experiments are all performed by the left arm, on the third day they are all performed by the right arm; on the second day the attunement experiments are performed by the left arm, while the pre- and post-attunement experiments are performed by the right arm; on the fourth day the attunement experiments are performed by the right arm, the pre- and post-attunement experiments by the left.

The subject is required to give his answers in terms of the second weight, according as it appears to him heavier or lighter than, or indistinguishable from, the first of each pair. The twenty days' judgments are here tabulated,

according as the corresponding answers are "lighter" (*l*), "indistinguishable" (*i*), and "heavier" (*h*):—

Order of Four-Day Groups.	Pre-Attunement.				Side "Attuned."	Post-Attunement.			
	Side of Body.	*l*	*i*	*h*		Side of Body.	*l*	*i*	*h*
First day	left	33	20	37	left	left	47	27	16
Second ,,	right	28	23	39	left	right	27	26	37
Third ,,	right	27	26	37	right	right	46	29	15
Fourth ,,	left	37	22	31	right	left	32	28	30

We see that it is only on the first and third days that the effect of the attunement experiments is manifest; the second weight appears lighter on these days. There is thus no evidence of extension of the attunement effect to the opposite side of the body.

This investigation was followed by others in which the paired weights of the attunement experiments, instead of being lifted in "light, heavy" sequence, were lifted in "heavy, light" sequence; and by others in which the two weights of the attunement experiments were equal. But into these and other experimental modifications we cannot enter here. Their general result has been to confirm the conclusion that the effects of attunement are confined to those muscles on which the attunement experiments have been performed.

The Comparison of Motor Attunement with the Effects of Stimulating the Visual Cortex.—A close analogy to this condition of motor attunement is to be found in the altered effects of unilateral stimulation of the visual cortex in the monkey, when this unilateral stimulation has been preceded by a period of bilateral stimulation of the cortex. Under

ordinary conditions, unilateral stimulation of the proper zone of the visual cortex produces movement of both eyes towards the opposite side of the body; whereas, during bilateral stimulation, the eyes assume the primary or a slightly convergent position. But it has been shown that after a period of bilateral excitation, subsequent unilateral excitation frequently produces a bilateral, not a unilateral effect. Instead of moving to one side, the two eyes fixate an imaginary object midway before them.

Now we have experimental evidence that the movement of the eyes to one side, usually produced by unilateral cortical stimulation, is not effected merely by contraction of the appropriate oculo-motor muscles. If those nerves, which supply solely this group of contracting muscles, be divided, the eye still behaves as before to cortical stimulation. This shows that normally the contraction of one group of ocular muscles is accompanied by active relaxation or inhibition of the opposing group of muscles.

On the other hand, during bilateral cortical stimulation, both groups of muscle are contracted. Consequently, it may be said of the above experiments that a preliminary series of bilateral stimulations is able to convert cortical impulses, which would normally have had an inhibitory effect, into impulses which have an excitatory effect, on the motor nuclei of the oculo-motor muscles. Apparently the synapses, between the nuclear and the cortical neurones (page 74), have acquired a definite setting or attunement, owing to their having been previously played upon in a definite manner.

A similar attunement may be supposed to have occurred in the weight-lifting experiments which we have had under consideration. It is not, as before, a change from inhibition to excitation, but a change in the intensity of excitation. Owing to this acquired setting or attunement, the volitional impulses that play upon the cortical arm centre no longer have their normal effect. The impulses, which descend

from the cortex to the spinal motor nuclei, are now either more powerful or less powerful than usual, according to the kind of attunement acquired.

The Comparison of Motor Attunement with the Association of Ideas.—In several respects, this condition of motor attunement bears a striking analogy to the establishment of association between two ideas. The tendency to a certain sequence of movement, weak following or followed by strong, may be acquired by weight-lifting, just as the tendency to a certain sequence of reproductions is acquired by learning. This analogy between motor attunement and the association of ideas is borne out in the following experiments.

The effects of one motor attunement may be apparently "counteracted" by another attunement subsequently acquired. If, for instance, a series of lifts of "light, heavy" pairs of weights (*e.g.* those of the attunement experiments described on page 221) be followed by a series of lifts of "heavy, light" pairs, an apparent "counteraction" of the first attunement is readily obtainable. This counteraction, however, occurs, even when a series of "equal weight" pairs is used in place of the "heavy, light" series. There is, therefore, no true counteraction; inasmuch as the first attunement disappears when the second is neither equal nor opposite to it.

We should be wrong, then, in supposing that the cortex returns to its primary neutral condition when one attunement is apparently counteracted by another. We must suppose that the two attunements neutralise one another by inhibition, rather than by annihilation. That such is the case is indeed proved by the fact that the older attunement—the attunement which is acquired first—outlasts the younger. It tends to return in course of time, although at first prevented by the inhibitory action of the younger attunement. Precisely analogous conditions have been experimentally shown to govern the relative strength of

the associations between syllables, *a–b* and *a–c*. They react on one another by inhibition, and, other things being equal, the older association outlasts the younger.

Moreover, it is found that the longer the time over which a given amount of practice (*i.e.* a given number of pairs of lifts) in acquiring a motor attunement is distributed, the stronger will that attunement, after not too short a pause, prove. Here again a striking analogy will be found to the relation between the strength of an association and the distribution of the repetitions whereby it has been acquired (page 171).

The Sense of Effort.—So far we have without question assumed that the effort of lifting, on the appreciation of which our judgments of weight are so dependent, is determined by the peripherally derived sensations of tension and movement. We have now to consider a totally different view, namely, that the efferent impulses, discharged from the motor cortical areas, give rise, at the moment of their discharge, to an experience (or "sensation") of effort, and that by the intensity of this experience we are informed of the force of the muscular contraction which we are employing, and hence of the weight of the object that we are lifting.

At one time, these were rival views and excited considerable controversy, but at the present day no one denies the importance of motor sensations. The evidence of disease and experiment, already quoted, is now too strong to be neglected even by the strongest partisan of the existence of the central "sense" of effort. The only question deserving of consideration is whether such a sense exists in us, in addition to kinæsthesis. If we admit it, we have at the same time to admit an essential difference between active and passive movements, between which we have already noticed a close resemblance (page 69). Nevertheless, it is quite conceivable that there may be difficulties in the way, the solution of which is only possible by an

assumption that we have a central sense of effort. We proceed, therefore, to discuss two such difficulties that have been brought forward.

Discussion of two Difficulties.—In cases of paralysis of a limb, the subject can make an effort to move the immobile limb, and he actually feels the effort which he has put forth. But because kinæsthetic sensations are no longer obtainable from the paralysed limb, we need not refer this sense of effort to a central origin. Any attempt at movement is never confined to a single muscle or limb, but always involves other parts of the body. The muscles of the opposite side of the body or of the respiratory system are commonly involved; when, for example, we endeavour to lift a weight, the glottis closes, the abdominal muscles and diaphragm contract. Moreover, many movements demand or are accompanied by the fixation of other parts of the body. That is to say, certain muscles must at the same time be thrown into contraction to prevent movement; and these may occasion the sensations of effort. We pass on to meet the second difficulty.

In a case of partial or complete paralysis of the external rectus muscle of one (say, the right) eye, the subject is unable to move the eye to the outer (right) limit of its normal range of movement. If, with the normal (left) eye closed, he endeavours to turn the eyes to the extreme right, instead of the right eye so turning, external objects in its field appear to be moving to the side. This apparent movement of the visual field, during the attempted contraction of a paralysed muscle, has been ascribed to the central sense of effort. It has been supposed that the effort leads the subject to believe that he has actually made the movement which he would under normal conditions have made, if objects were passing before his gaze; whereupon he unconsciously infers that the objects in his visual field are moving.

But this explanation neglects the movements of the

healthy closed eye. While the right external rectus is paralysed, the left eye has necessarily been moving to the right, and it is in the highest degree probable that the apparent movement of the field of the right eye is due to confusion between the experiences of the two eyes, always so closely associated with one another (cf. exp. 127). The subject believes that the right eye, whereas in reality the left eye, has moved to the right. The explanation also neglects the effects due to the relaxation of the internal rectus in the right eye (page 225).

When both eyes are open, either the illusion does not occur, or there is double vision (diplopia) and the illusion is confined to the paralysed eye. That is to say, in the one case the subject has come to neglect the visual experiences of his paralysed eye; in the other the motor sensations of the left eye serve to interpret in different ways for each eye the now independent experiences of the retinæ. Again, then, there is not sufficient cause to assume the existence of central sensations of effort.

Other Difficulties.—Nor would it be easy to comprehend the physiological basis of such central experiences of effort, even if, as is far from being the case, the necessity for their existence had been psychologically proved. We should have to assume that the motor nervous impulse, at the moment of its discharge from the cortex, was directed towards some cortical sensory centre. Now, whether, as seems most probable, the sensory fibres of the motor apparatus terminate in special kinæsthetic areas of the cortex, or whether, as others believe, they communicate directly and solely with the cortical motor areas, in any case there is unquestionably a passage of nervous impulses from the sensory towards the motor neurones; and, so far as we know, the direction of impulses across a synapse is irreversible.

We should expect that, if such backward discharges were possible, they would not evoke "sensations of effort," but that they would rather revive images of earlier, or

produce ideas of the coming, movements. We know, however, that the true order of events is precisely the opposite. It is in the attention to images of the anticipated movement, and in the passage of these images into movement, that the volitional execution of unpractised movements consists.

We may conclude, then, that what effort of central origin there is in movement is of the same nature as the effort which distinguishes active from passive movement, and characterises all higher forms of mental activity, for example, reasoning or imagination. It is the effort inherent in every conative process.

BIBLIOGRAPHY.

G. E. Müller u. F. Schumann, "Über d. psychol. Grundlagen d. Vergleichung gehobener Gewichte," *Arch. f. d. ges. Physiol.*, 1889, xlv. 37. A. D. Waller, "The Sense of Effort," *Brain*, 1891, xiv. 179. S. Exner, *Entwurf zu einer physiol. Erklärung d. psychischen Erscheinungen*, Wien, 1894, i. 170. C. E. Seashore, "Measurements of Illusions and Hallucinations in Normal Life," *Stud. Yale Psychol. Lab.*, 1895, iii. 1. Flournoy, "De l'Influence de la Perception Visuelle des Corps sur leur Poids Apparent," *L'Année psychol.*, 1894, i. 198. Laura Steffens, "Über die motorische Einstellung," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1900, xxiii. 241. W. Wundt, *Grundzüge d. physiol. Psychologie*, Leipzig, 1902, 5te Aufl., ii. 25. R. S. Woodworth, *Le Mouvement*, Paris, 1903.

CHAPTER XVII

ON LOCAL SIGNATURE

Local Sign.—When two sufficiently distant points, either of the retina or of the skin, are similarly excited by the same stimulus, the two resulting sensations, retinal or cutaneous, differ in respect of a character which is termed "local signature." Through differences of "local sign" we become aware of differences in the direction of the source of light, or in the point of application of the stimulus to the skin.

The Cutaneous Spatial Threshold.—The degree, to which neighbouring points on the skin differ in local sign, varies within wide limits over the body surface. A measure of it is afforded by the "spatial threshold," the liminal distance necessary to produce a double touch (exp. 103). When two points on the skin are simultaneously touched, they must be separated by the following distances in order that the touch may be felt as double :—

Region of Skin.	Distance of the Points.
Tip of tongue	0·1 cms.
Tip of finger (palmar surface) . .	0·2 ,,
Lips (outer surface)	0·5 ,,
Tip of nose	0·7 ,,
Tip of finger (dorsal surface) . .	0·7 ,,
Lips (inner surface)	2·0 ,,
Back of hand	3·2 ,,
Forearm, leg, and sacrum . . .	4·0 ,,
Sternum	4·5 ,,
Spine	5·4 ,,
Arm and thigh	6·8 ,,

Owing to individual variations, these data are only approximate. They refer to distances taken in a longitudinal direction upon the region mentioned. When, instead, the two points are applied transversely, the spatial thresholds are less than those above given.

A far lower threshold is obtainable when care is taken to confine the stimulation to touch spots. Indeed, it has been said that in regions where touch spots are sufficiently scattered to permit of their separate investigation, the local sign of individual touch spots is so characteristic, that, when touched successively, each touch spot is distinguishable from its neighbour. Whether touch spots are selected or not, the threshold is always lower, when the two points are applied successively, than when they are applied simultaneously, especially if the first point be removed before the application of the second point.

Introspection near the Threshold.—Even when the distance between two points, simultaneously applied to the skin, is not wide enough to produce a double touch, the experience may nevertheless be different from that produced by the application of a single point. Although it is an experience of single touch, yet it is altered in respect of a character which has been called "extensity." The touch seems no longer limited to a point. It is now blurred, spread out, and referred to a wider area. Ultimately, as the distance is gradually increased, this diffuse single touch gives way to an experience of double touch. We have here an indication of one of the ways in which the spatial threshold may become lowered with practice. The individual, although he does not feel two distinct touches, has, nevertheless, an experience, sufficiently different from that produced by the application of a single point, for him to be able to infer that two points are being applied to his skin. This improved power of interpretation may in part account for the abnormally low threshold which obtains among the blind.

When practice has brought about a reduced spatial

threshold in one cutaneous area, a like improvement is manifested in a symmetrically situated area on the opposite unpractised side of the body. This is, perhaps, related to a morbid condition, known as "allochiria," in which the patient is in doubt as to which side of his body is touched, often referring the touch to the opposite side. But the physiological mechanism, underlying this relation between corresponding or symmetrical areas of the body, is at present unknown.

Variations of the Spatial Threshold.—The spatial threshold varies with the general condition of the individual. Narcotics cause it to rise. It has been employed unsatisfactorily as a test of mental fatigue (page 190).

Local conditions no doubt affect the spatial threshold. It is raised by coldness or anæmia of the part, or by the application of irritants, and it is lowered by warmth, hyperæmia, or by local friction.

Loss of the mobility of a limb (*e.g.* through fracture) is apt ultimately to produce a rise in the spatial threshold. Throughout the normal body, a similar correlation is observable between the height of the threshold and the exploring activity of the region; the spatial threshold on the limbs, for example, decreasing towards their free extremities.

Cutaneous Threshold for Lines.—We have already seen (page 232) that two points, simultaneously applied, may give rise to an experience of increased extensity, when their distance apart is insufficient to produce an experience of double touch. This suggests (and it is experimentally verifiable) that the shortest line, which can just be appreciated when applied to the skin, is less than the distance necessary to distinguish clearly two simultaneously applied points. When, however, the subject is in addition required to judge the direction of the line, the liminal length of the line differs little from the liminal distance between two simultaneously applied points.

The apparent length of a line, or of the distance between

two points, applied to the skin, depends on the spatial threshold of the cutaneous area under investigation. According as the differences in local signature are coarse or fine, the distance appears smaller or greater (exp. 104).

A similar result holds for movement. The apparent rate of a point moving along the skin waxes and wanes with the rise and fall of the spatial threshold (exp. 104).

The Histological Basis of the Spatial Threshold.—Once acquired, cutaneous localisation is evoked not only when the skin is stimulated, but also when any part of the afferent peripheral, or central, nervous system, which is functionally connected with the skin, is stimulated. Thus stimulation of the nerves within the stump of an amputated limb usually causes a localisation of the sensation in the extremities of the lost member. Such an illusion may persist, though somewhat enfeebled, throughout life. The amputated extremity, to which the sensations are referred, often seems as if it were reduced in size and lay nearer than usual to the stump. This apparent nearness is, perhaps, the result of the loss of sensation from intermediate regions. The reduction in size would then arise from an incorrect inference of the size of the familiar object, based on its apparent distance.

It is impossible to accept the view that the cutaneous surface contains a number of anatomical areas, each supplied by a different nerve fibre, and that a double touch is experienced only when the applied points rest on different anatomical areas. In the first place, there is always great overlapping in the nerve supply of any given cutaneous area. A fibre *B* subdivides to supply not only the area *b* but also the adjoining areas *a* and *c*; a fibre *C* similarly supplies the areas *b* and *d*, as well as *c*. In the second place, were the view just mentioned true, we should expect that, when the distance between the two applied points falls just short of the diameter of such an anatomical area, the same equidistant stimuli would give rise to a double touch

if they lay on different areas, and to a single touch if they lay on the same area; whereas, in fact, nothing of this kind occurs.

There are better reasons for supposing that a given point of the skin, when stimulated, evokes not only its own local sign, but also to a less extent the local signs of neighbouring points; and that the degree to which the latter are evoked decreases with their distance from the point of stimulation, and possibly with the delicacy of the local signature in the district.

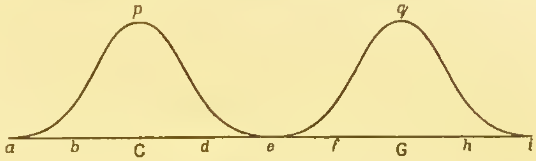

FIG. 7, I.

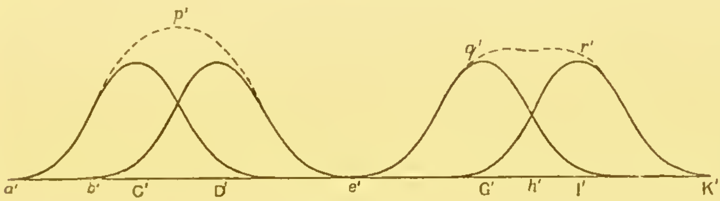

FIG. 7, II.

If we represent the degree to which two cutaneous points *C* and *G* evoke the local signs of neighbouring points by erecting ordinates from *a b C d e* and *e f G h i* (fig. 7, I.), joining the ends of these ordinates to form the curves *a p e*, *e q i*, clearly there is no overlap in local sign, and the double touch is under these conditions clearly recognised. If, on the other hand, the points of stimulation be closer together, as *C′* and *D′*, or *G′* and *I′* (fig. 7, II.), their simultaneous excitement must give rise either to a single less punctate touch, as at *p′*, or to a broad blur, as at *q′ r′*; the dotted

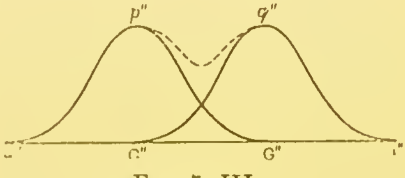

FIG. 7, III.

lines representing the result of compounding the two curves. Such a condition cannot give rise to an experience of clearly double touch; whereas, when the peaks are sufficiently distinct, as at C'' and G'' (fig. 7, III.), the threshold may conceivably have just been reached.

This scheme enables us to understand the increase of extensity which is experienced when the two points, as at G' and I', are not sufficiently distant to allow of the touches appearing double. Here points of the skin lying between G' and I' have their local signs evoked in almost equal degrees, as shown by the dotted portion q' r'. The conditions are almost identical with those that would arise, were a line to press on the skin between these two points.

If we are right in supposing that a point of the skin when touched evokes not only its own local sign, but also the local signs of neighbouring points, we have yet to explain why this should be the case. It may be conceived as the result of association. The point C has so often been touched simultaneously with a b d e, and their local signs have been so often evoked simultaneously, that ultimately stimulation of C alone calls forth both its own and the neighbouring local signs. Or, with more reason, the phenomenon may be attributed to the gradual differentiation of local signature, which must occur during the very early life of the individual. We may suppose that at first the cutaneous areas, within which no perceptible differences of local sign exist, are comparatively large, and that as these differences become evolved the old sharing of local signature nevertheless persists. In other words, the curve, expressing the degree to which any point C evokes the local sign of neighbouring cutaneous points, is at first broad and almost peakless, and it gradually rises to acquire an apex, as shown in fig. 7, I.

Relative and Absolute Localisation on the Skin.—So far we have dwelt chiefly on the discrimination of two touched points from one another. We have now to examine the

conditions which determine the localisation of the two points "relatively" to one another, or the localisation of either of the points "absolutely" on the body surface.

In this connection, Aristotle's experiment and its modifications (exp. 105) are of interest, for they show how much our localisation of two points on the skin relatively to one another depends on, and hence has been derived from, the normal position of the body. That visual imagery need play no essential part in the genetic basis of localisation, is shown by the fact that the illusions of Aristotle's experiment are obtainable in individuals who have been blind from infancy. In normal people, however, visual imagery is of undoubted importance both as regards the relative localisation of two points and as regards the absolute localisation of a single point on the skin. The more help a subject is allowed from visual experiences, the more accurate becomes his "absolute" localisation of any stimulated cutaneous area (exp. 106).

Absolute localisation is also aided by kinæsthetic (motor) sensations. If one of the subject's fingers be touched when his eyes are closed, he is sometimes apt to localise the stimulus on the correct part of the finger, but on another finger. The error is often avoidable if he be allowed to move one or other of his fingers, not necessarily that which is touched. The value of kinæsthetic sensations in localisation appears to be evident in the following pathological case. In one limb, the cutaneous sensibility in which had become slightly and the kinæsthesis enormously reduced, the error of localisation was far greater than on the limb of the opposite side, in which the sense of movement was preserved but cutaneous sensibility was very much reduced.

Thus absolute localisation clearly involves many other factors than that of local signature. Otherwise, indeed, we might expect that, if a point B were located at A, the point A when touched would, by reciprocal confusion, be located

at *B*. On the contrary, the error of localisation has generally a constant direction. Further, the degree of error is found not to be proportionate to the spatial threshold.

The Basis of Cutaneous and Retinal Local Signature.—We have left on one side the problem, how cutaneous and retinal points acquire their local sign.

Lotze, to whom we owe the term "local sign," supposed that the differences in cutaneous local sign are the result of those differences in structure and in nerve supply of the skin surfaces, by virtue of which the direct and associated sensations, produced by stimulation of one point, differ from those produced by stimulation of another, *b*. Others have attributed local signature solely to the various impulses to movement, or to the kinæsthetic sensations derived from movement, which a touched spot of the skin calls forth.

Hering supposes that retinal local signs are innate, each point of the retina differing from other points in height- or breadth-value, or in both values. A detailed examination of Hering's views is impossible here. But stress may be laid on his supposition that these congenital differences of local sign are of purely retinal origin, and that they reflexly produce the movements of the orbits leading to direct fixation.

Others have supposed that retinal local signs are due to the kinæsthetic sensations arising from orbital movement. It has been argued that, when a ray of light falls upon a retinal spot, a movement of the eye, accompanied by definite kinæsthetic sensations, occurs in order that the image may be brought to fall on the fovea. According to this view, the kinæsthetic sensations, varying according to the distance and direction of the necessary orbital movement, become associated with the retinal spots which, when stimulated, produce them; so that, finally, although no eye movements may be made, stimulation of various retinal spots yet evokes their characteristic local signs. Here we approach Lotze's standpoint, who regarded retinal local

signs as the result of centrally aroused impulses to movement,—a standpoint fundamentally different from Hering's, who, as we have just seen, regarded retinal local signs as the cause of movement.

Against the kinæsthetic basis of retinal local signature several weighty objections may be urged. In cases of recovery from congenital blindness, the individual is at once able to recognise differences in size and in form of images received by his retina. So instantly is a round object seen to differ from a triangular one, that the judgment is clearly independent of the training which would be needed before the eyes could be moved in a fashion orderly enough to follow the outlines of the object.

Again, in certain cases of retinitis, where the elements in the affected region of the retina are abnormally crowded together or separated by inflammatory products, a local "metamorphopsia," or distortion of vision, is produced. It arises from the fact that the displaced retinal elements retain their normal local sign under these conditions. A line, whose image falls on the affected area of the retina, appears bent in or bowed out, according as the elements are unduly separated or contracted. Such distortion would surely be corrected in time if motor sensations were the basis of local signature. In point of fact, it is said to persist for months or even for years,—indeed, as long, perhaps, as the pathological condition remains.

Lastly, attention may be called to the fact that lines which subtend less than an angle of one minute can be spatially distinguished by the eye. If such discrimination depended for its origin on kinæsthetic sensibility, then the delicacy of kinæsthesis in the orbits must be almost incredibly greater than that in any other part of the body.

We can hardly avoid the conclusion that the local signature of the retina is innate, and that the basis of it is to be sought rather on the sensory than on the motor side of the retinal sensori-motor mechanism. A similar conclusion

is probably true as regards the skin. Yet even so, we must admit that, in conjunction with these innate differences of local signature, kinæsthetic sensations play an important rôle, during infancy, in the elaboration and orderly arrangement of spatial relations. To realise the importance of the rôle, one has only to attempt to conceive what sort of space a subject would create for himself were he endowed with visual and cutaneous sensibility, but congenitally deprived of kinæsthesis.

Moving Retinal Images.—When the image of a moving object falls on the stationary retina, it is found that the smallest rate of movement which can be detected is dependent upon the simultaneous presence of stationary objects. An angular movement of between 1′ and 2′ per second can be immediately detected when the marks on a rotating drum are regarded. This threshold, however, is immediately raised to about 20′ per second when the drum is viewed through a slit so that surrounding resting objects are cut off from view. But there is evidence that even under these conditions the stationary margins of the slit serve as a guide. For when a glowing thread is alternately slowly moved and brought to rest in a dark room, the movement can be detected only with difficulty, and illusions of movement frequently occur. The latter have been attributed to involuntary and unconscious movements of the eyes, but this has been denied by other observers, who have termed them " autokinetic " sensations. A stationary point of light, regarded in a dark room, may appear to move with an angular velocity of from 2° to 3° per second.

The threshold for movement is higher in peripheral than in foveal vision. We are ignorant of any influence of dark adaptation upon the threshold. Moving objects unquestionably travel with apparently greater speed in peripheral than in foveal vision.

When part of the visual field is moving, it tends simultaneously to induce an apparent contrary movement in surrounding stationary parts of the field (exp. 108).

Retinal After-sensations of Movement.—A transient "positive" after-effect has been described but disputed. It has been said to occur when the eyes are closed after having followed a moving object, or after having at rest received the image of a moving object.

The "negative" effects, which are easier to observe, are not open to dispute. Resting objects, when regarded after the eyes have been watching moving objects, appear to be moving in a direction contrary to the previous movement (exp. 107, 108). This after-effect was attributed by Helmholtz to unconsciously continued movements of the eyes; the subject believing that his eyes are stationary, and so inferring that the field is moving in the reverse direction.

Such an explanation, however, fails to account for the following facts. If a black spiral band painted on a white disc be slowly rotated and be fixated during rotation, the disc, on being brought to rest, will show most striking changes which no after-movements of the eyes can explain. It will appear to contract or to expand with a peculiar streaming movement, according to the direction of rotation. If only part of the retina receive the image of the moving field, the after-movement is confined to the part stimulated (exp. 109).

If a disc be prepared with two different superposed spirals, or with a spiral which changes its direction several times as it proceeds from the centre to the periphery of the disc, the various directions of movement are simultaneously represented in the after-effect. When two contrary movements are presented, one to one eye, the other to the other, the after-effects may neutralise one another; or a single after-movement, the resultant of the two components, may be seen; or now one after-movement, now the other, may occur alternately.

Such results appear to show a binocular relation not unlike that which, as we shall see, obtains in binocular colour combination and contrast (pages 280, 281). They would lead

us to ascribe a sensory character to our visual (and perhaps also to our cutaneous) experiences of movement, and generally to compare negative after-movements to negative after-images, ascribing a like cerebro-retinal basis to each. Certainly from the phylogenetic standpoint the visual perception of movement must be as primitive as, and perhaps more important than, the appearance of well-defined visual images.

BIBLIOGRAPHY.

E. H. Weber, "Der Tastsinn u. d. Gemeingefuhl" in Wagner's *Handwörterbuch d. Physiol.*, Braunschweig, 1846, iii. (2) 481. R. H. Lotze, *Medicinische Psychologie*, Leipzig, 1852, 325. E. Hering, *Beiträge zur Physiol.*, Leipzig, 1864, Heft v. V. Henri, *Ueber d. Raumwahrnehmungen d. Tastsinnes*, Berlin, 1898. A. Binet, "La Mésure de la Sensibilité," and other articles, *L'Année psychologique*, 1903, 9me Année, 89. W. McDougall, *Reports of the Cambridge Anthropological Expedition to the Torres Straits*, 1903, ii. 189. C. Spearman, "Analysis of Localisation, illustrated by a Brown-Sequard Case," *Brit. Journ. of Psychol.*, 1905, i. 286; "Fortschritte auf d. Gebiete d. Psychophysik d. raumlichen Vorstellungen," *Arch. f. d. ges. Psychol.*, 1906, viii. (Literaturbericht). E. Jones, "The Precise Diagnostic Value of Allochiria," *Brain*, 1907, xxx. 490. A. v. Szily, "Bewegungsnachbild u. Bewegungscontrast," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1905, xxxviii. 81; "Zum Studium d. Bewegungsnachbildes," *Ztsch. f. Sinnesphysiol.*, 1907, xlii. 109. A. Basler, "Ueber d. Sehen v. Bewegungen," *Arch. f. d. ges. Physiol.*, 1906, cxv. 582; *ibid.*, 1908, cxxiv. 313, L. Ruppert, "Ein Vergleich zur d. Distinktionsvermögen u. d. Bewegungsempfindlichkeit d. Netzhautperipherie," *Ztsch. f. Sinnesphysiol.* 1908, xlii. 409.

CHAPTER XVIII

ON SENSIBILITY AND SENSORY ACUITY[1]

Discrimination as a Factor in Sensation.—The sensations of the so-called intrinsic light in the retina, the auditory sensations that occur in absolute silence, the temperature sensations that accompany blushing or pallor, are all illustrations of the fact that, however carefully the sense organs be guarded from external stimuli, they cannot be considered to be absolutely at rest. The effect of applying an external stimulus to an apparently resting sense organ is rather to alter the contribution made by that organ to the sum total of experience than to transform it from a state of absolute quiescence into one of activity. In determining, for example, the acuity or sensibility of hearing, the attitude of the subject is found to involve discrimination between his auditory experiences before and those at the moment of, the presentation of the stimulus. In general, a test for sensory acuity or sensibility entails sensory discrimination.

The Complexity of the Conditions determining Sensibility.—Sensibility is dependent not merely on the condition of the sensory structure which is under examination, but also on the condition of neighbouring sensory structures, and indeed of all other parts of the nervous system. The sensibility of a given retinal area, for example, varies with the state of adaptation of that area and of the surrounding areas of the retina. It depends also on the presence, and on the nature and intensity, of sensations which are

[1] See footnote to Chapter III.

simultaneously or have recently been evoked from other end organs. It is affected by general or by local fatigue, by attention, practice, expectation, and interpretation. Sensibility, in fact, varies with the total mental state at the moment of determination.

[On physiological and anatomical grounds we may be disposed to regard sensation as the simple reaction of the sensory apparatus. We may attempt to distinguish between the sensibility of the sensory organ,—dependent on simpler, more peripheral conditions,—on the one hand, and the effect of that sensibility on consciousness,—the resultant of far more complex factors,—on the other. From this standpoint, sensibility may conceivably remain unchanged when a stimulus, previously effective, is now ineffective. Such alteration in the efficiency of the stimulus may be considered due merely to changes in the higher parts of the brain.

But, from the psychological standpoint, we have to remember that the occurrence of a sensation implies a change in the complex totality of consciousness, a change modified by past and present experiences, and modifying present and future experiences. Consequently, if from one aspect we are led to regard sensations as a number of elementary independent entities, from the other we are led to regard them as modifications of the Ego. Microcosms there may be within the macrocosm of the Ego, but the normal Ego has no knowledge of any consciousness save its own. From the psychological standpoint, the activity of the parts is inseparably bound up in the activity of the whole.]

Visual Acuity. — Visual acuity is measured by the angle subtended at the eye by two points which can be just distinguished. It is commonly determined by means of "test-types," composed of letters of different size, which are numbered according to the distance in metres at which they should be correctly read by persons possessing "normal" visual acuity. At this distance the height of a letter

subtends an angle of five minutes, and the smaller squares within the outline of a letter subtend an angle of one minute at the eye. An angle of one minute is approximately that which is required for the clear discrimination of fine black lines, separated by a distance of their own diameter from one another.

Conducted in this way, the determination of visual acuity involves many complex factors. Variations in brightness, contrast, and irradiation are the most obvious of these. The general illumination has an important influence. The acuity determined in a room is very different from that determined out of doors.

Both indoors and especially in the open, many people have a visual acuity exceeding what is commonly accepted as the normal. This is partly due to the fact that the letters may be read even when their form is not perfectly seen. The individual is able, after a little practice, correctly to distinguish similar letters from one another, not because he has a clear image of their respective outlines, but because he is able to draw inferences. He notes, for example, that the side of a P contains a dim but continuous blur, while in an F there is a clearly open space. It is evident, then, that the distance at which letters of a given size can be distinguished depends upon the particular letters used in the test, and upon the degree of the subject's familiarity with them.

To obviate the individual differences thus resulting from illiteracy, test types composed of a single form or letter, *e.g.* [, E or C, have been constructed, the form or letter varying only in size and position (exp. 111). But even with such single forms, interpretation and inferences are still possible. The subject is able to guess the position of the letters correctly when he receives only a very blurred image of their form.

Different arrangements of black (or white) dots on a white (or black) background,—various dots being exposed

and counted at different distances,—have been also employed for the estimation of visual acuity. But here again different results may be reached by two persons who, from the strictly "physiological" standpoint, have equal visual acuity. The one, an illiterate, has greater difficulty of counting than the other, a more cultured individual; or the one makes no attempt, while the other (owing to greater interest and perhaps to greater intelligence) leaves no effort unspared, to interpret as dots what he but dimly sees; the blunt stolid character of the one leading him to describe nothing but what is obvious and certain, the highly imaginative character of the other inducing him to go further by discrimination and interpretation.

Visual Efficiency.—It is important to distinguish between visual acuity and what has been termed "visual efficiency." The latter makes no allowance for errors due to refraction or to other ocular defects in front of the retina, whereas in the determination of visual acuity these disturbances are presumed to be absent, or to have been eliminated by the use of glasses.

Visual Sensibility.—Visual acuity, as already defined, must be further distinguished from "visual sensibility." This is measured by the lowest intensity of light which can produce a sensation, when it falls on a given area of the retina. Visual sensibility increases with the extent of the area stimulated, especially in the periphery of the retina. It increases enormously (in some cases even eight thousandfold) with increased dark adaptation of the eye, if the area stimulated lie outside the fovea. While in the bright adapted eye the fovea is most sensitive, in the dark adapted eye the extra-foveal area of the retina is most sensitive. Indeed, astronomers have for long been aware that a dim star can be best seen not by direct vision, but by fixation of a point which lies to one side of the star. The temporal half of the bright-adapted retina has been found to be less sensitive to light than the nasal half.

The comparative sensibility of the eye for different colours has been estimated by observing the point at which the various colour sensations disappear, as spectral hues are gradually reduced in intensity. Red disappears first, then yellow and blue, next violet, while green persists longest. The results, however, are dependent on the saturation of the colour, on the size of the field, and on the local and general condition of the retina.

Auditory acuity.—The estimation of auditory acuity—or sensibility—(for in all sense organs other than the eye the two terms are synonymous) is complicated by many of the factors which, as we have seen, influence the determination of visual acuity. Persons whose hearing is obtuse differ widely in their sensitivity to different kinds of auditory stimuli, *e.g.* to words, tones, and noises. This is, in great part, due to individual differences in interpretation.

The human voice is obviously a very uncertain source of stimulus. It varies as regards distinctness, loudness, and quality not only in different individuals, but also in the same individual, however careful he be, at different times. Clearly, too, some words are audible at a greater distance than others, according to the nature, arrangement, and relative number of vowels and consonants contained therein.

Whatever be the form of stimulus, its constancy and uniformity are of great importance. For this reason, the sound resulting from the fall of an object from a given height appears, at first sight, to be especially suitable. The intensity of the stimulus can be varied either by altering the height from which the body is let fall, or by increasing or decreasing the distance between the instrument and the individual's ear. The disadvantages of such a method of estimation arise partly from alterations in the pitch or quality of the sound according to the acceleration of the falling body at the moment of impact, and partly from the complex nature of the sound, which consequently appears to vary in quality according to its distance from the ear

(page 291). Fairly satisfactory results can be obtained by the use of Politzer's acoumeter or of a stop-watch (exp. 112).

Auditory acuity has been also tested by means of a stationary vibrating tuning fork, which is allowed to "ring off" until the subject no longer hears it, or by means of a watch, which is gradually removed from the ear until the ticks are inaudible. But estimations based on such methods are in various degrees unsatisfactory.

A very great difficulty arises through the variable play of certain internal and external factors, the acuity changing from hour to hour, or from day to day, according to the condition of the individual, and according to the disturbing influence of adventitious sounds.

At or near the threshold the judgments of the subject are complicated by the influence of expectation and of auditory memory images. He attributes to subjective experiences those which really are of objective origin, and declares that he hears the sound during periods of actual silence.

At present we know little of the relation between auditory acuity and differences of pitch. We are aware that both the low and the high limits of the tone range are dependent on the intensity of the tone stimuli (page 36), and there is reason to think that, when two tones of equal physical intensity are successively sounded, the higher tone gives rise to the more intense sensation.

Olfactory acuity.—Olfactory acuity may be measured either by Zwaardemaker's olfactometer (fig. 8), or by glass vessels some of which contain water, others the odorous solution in different strengths (exp. 113).

Zwaardemaker, employing a rubber tube as the standard substance for his olfactometer, found that individuals who had average olfactory acuity could just detect its odour when it was drawn out to a distance of seven millimetres beyond the inner glass tube. This length he took as his unit, calling it an "olfactie." An individual who fails to

detect the odour until twenty-one millimetres of the rubber tube had been exposed is said to have an acuity of three olfacties. Tubes of various solids (*e.g.* beeswax, paraffin) have been employed. Odorous liquids may be also used, a porous tube being soaked in a solution of the substance before it is placed over the inner tube of the instrument. Care must always be taken to cleanse the inner tube repeatedly.

Olfactory acuity, as thus determined, varies in different individuals according to the odour which is employed. Those who have unusually keen sensibility for one odour may have only normal or even subnormal sensibility for others.

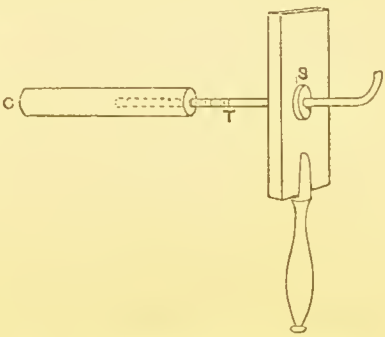

Fig. 8.—Zwaardemaker's Olfactometer. This instrument consists of a cylindrical tube, *C*, containing the odorous substance and fitting over the graduated glass tube, *T*, which passes through the wooden screen, *S*, to be inserted into the nostril of the observer.

A difficulty often arises in the estimation of the threshold owing to a change in the character of the odour, when the vapour is in a very diluted state. Under these circumstances the subject may assert that he can smell something, but that it is not at all the ordinary odour of the substance which he is expected to smell. Here again individual differences in interpretation and inference have ample play.

Gustatory Acuity.—Gustatory acuity may be tested by the application of solutions of various strengths either to individual papillæ or to larger areas of the tongue or other neighbouring, similarly sensitive, regions. The principal factors, which are liable to disturb the estimation, have been already indicated.

Tactual Acuity.—Tactual acuity, so far as it concerns the sensibility of the skin to light touch, may be estimated by

means of hairs or glass fibres which have been previously standardised, or by carefully applying plates of varying sizes and weight, previously warmed to the skin temperature. It is found that the threshold varies according to the region, the extent, and the condition of the cutaneous area which is stimulated, and according to the rate of application of the stimulus. Up to a certain limit a small pressure applied to a larger area will be effective when the same pressure applied to a smaller area proves subliminal. Increased tension or previous friction of the skin raises the threshold of that area.

The closeness of aggregation and the variations in sensitivity of the touch spots, and the thickness of the skin differ in different regions. Movement of the hairs of the skin is from three to twelve times more effective than cutaneous pressure in producing a sensation of touch.

The following pressures per square millimetre express the touch thresholds for different regions of the body, as determined by stimulation with glass wool fibres, the surface of contact varying from $\frac{1}{500}$ to $\frac{1}{16}$ sq. mm.

2	grams—	Tongue and nose.
2·5	„	Lips.
3	„	Finger tip and forehead.
5	„	Dorsal surface of finger.
7	„	Palm, arm, and thigh.
8	„	Forearm.
12	„	Occiput.
16	„	Calf and shoulder.
26	„	Extensor surface of arm, abdomen, abductor surface of thigh.
28	„	Shin and sole.
33	„	Extensor surface of forearm.
48	„	Loins.

Thermal Acuity.—Thermal acuity may be similarly estimated by punctate exploration or by the application of properly warmed or cooled surfaces to larger areas of the

skin. It is impossible to determine the threshold of thermal sensibility without taking into account the temperature of adaptation of the area under examination (page 16). The sensitivity varies according to the duration of application of the stimulus, the region, extent, and condition of the cutaneous area.

The clothed parts of the body, *e.g.* the nipples and the loins, are generally more sensitive to cold and heat than the unclothed parts. The lower eyelids, cheeks, and temples are marked exceptions to this rule. The middle line of the body is relatively insensitive to temperature. The sensitivity increases from the far extremity of the limbs towards the trunk.

Algesic Acuity.—The sensibility to pain may be similarly tested by punctate or by surface exploration, the stimulus being generally a prick or a severe pressure. The threshold for pain is higher than that for touch, but the ratio of the two thresholds varies enormously in different regions of the body. The threshold is highest on the buttock, thigh, penis, ankle, and palm, and is lowest on the temple, dorsal surface of the fingers, and tip of the tongue. It is higher on the flexor than on the extensor surface of the limbs, and is highest where the skin is thick, or where it overlies thick muscle, and does not overlie bone. The threshold is higher among primitive than among civilised people.

Kinæsthetic Acuity.—The threshold of kinæsthesis may be determined by observing the smallest appreciable amount of movement, when the eyes are closed and all adventitious influences are eliminated (exp. 44). But the liminal movement depends so much on the rate at which that movement takes place that the latter must be studied conjointly with the former.

If account be taken of both these factors, the kinæsthetic sensibility of different parts of the body may be compared. It appears that our appreciation of movement

in the proximal joints (the shoulder or hip) is keener than in the more distal ones (the finger or ankle).

Sensory Adaptation and Fatigue.—We have already (page 243) called attention to the important influence of sensory adaptation and sensory fatigue upon sensibility. The broad difference in nature between these two factors is sufficiently obvious, but the differentiation of their effects from one another is often extremely difficult. Sometimes the one, sometimes the other, is the preponderating factor, while in the case of some senses it is at present impossible to determine whether the condition be one of adaptation or fatigue.

In the retina, sensory adaptation is so prominent (pages 79, 96), that the evidence in favour of fatigue is extremely slight. The eye endures the continuous light of a northern summer without signs of exhaustion. The effects of wearing coloured glasses (exp. 114) are clearly ascribable to adaptation rather than to fatigue.

In the case of the skin, on the other hand, the hot and cold spots are extremely fatigable. They appear to react explosively and then to require time for the regeneration of their functional powers. But, in addition to this liability of the spots to fatigue, we have ample evidence of adaptation in the case of cutaneous sensations of temperature (page 16). Sensory adaptation is also of great importance in tactual sensibility, and probably occurs in a certain degree in sensations of pain.

Tones which are near the upper limit of hearing give rise to intermittent sensations. It is, however, more probable that the interruptions are due to external physical conditions rather than to sensory fatigue. Other evidence, brought forward in favour of auditory fatigue, may be as well adduced in favour of sensory adaptation (exps. 117, 118).

The play of sensations, brought about by the prolonged application of an odorous stimulus (page 115; exp. 83),

may be most readily ascribed to fatigue, but the possible influence of adaptation cannot be overlooked.

[*Other Forms of Adaptation.*—In the case of labyrinthine sensations, the form of adaptation which occurs is somewhat different from the strictly sensory form. During rest after a prolonged sea-voyage or railway journey, the after-effects of such adaptation are too well known to need description.

Yet another form of adaptation occurs, as we have seen, in muscular activity. The system becomes attuned to producing a particular degree of muscular contraction (page 222) or a particular sequence of contractions (page 221); and consequently, when a heavier (or lighter) load is subsequently lifted, insufficient (or excessive) muscular force is applied. This occurs in spite of the recognition, through touch or vision, of the altered size of the load. The load is therefore judged to be heavier (or lighter) than it really is.

Another form of adaptation is instanced in the effects of continuously wearing glasses which invert the field of vision. In course of time, the subject's movements become adapted to the changed position of seen objects. The results of such adaptation are very conspicuous when at length the glasses are discarded.

In the ear, adaptation of a still higher order is met with, which, like the strictly sensory form, masks the fatiguing effects of sensory activity on consciousness. A tone may be sounded incessantly for hours, and yet it remains audible. To such a continuous auditory stimulus we become adapted; ultimately we cease to notice it. But we may become aware of it at any moment through a passive or voluntary change in attention.]

BIBLIOGRAPHY.

H. Zwaardemaker, *Die Physiologie d. Geruchs*, Leipzig, 1895, 78. W. McDougall, *Reports of the Cambridge Anthropol. Expedition to the Torres*

Straits, Cambridge, 1901–3, ii. 194. C. S. Myers, *ibid.*, 143 ; W. H. R. Rivers, *ibid.*, 13, "Observations on the Senses of the Todas," *Brit. Journ. of Psychol.*, 1905, i. 321. E. Toulouse, N. Vaschide et H. Piéron, *Technique de Psychologie Expérimentale*, Paris, 1904, 49. B. R. Andrews, "Auditory Tests," *Amer. Journ. of Psychol.*, 1904, xv. 14 ; 1905, xvi. 302.

CHAPTER XIX

ON EXPERIENCES OF IDENTITY AND DIFFERENCE[1]

Weber's Law.—It is a familiar condition that two stimuli must differ at least by a minimal amount, in order that we may become aware of their difference. That difference which, throughout a long series of trials, turns out to be as often appreciable as inappreciable, we have termed "the liminal stimulus difference" or "the differential threshold of the stimulus" (pages 201, 210). A difference which exceeds this liminal value becomes more often appreciable than inappreciable.

If i be the magnitude of a given stimulus, and if $\triangle i$ be its differential threshold, it is found that $\frac{\triangle i}{i}$ has an approximately constant value, except for extremely large or extremely small values of i. This discovery was made over seventy years ago by Weber, when he was determining just appreciable differences between certain stimuli. He found that a practised subject, who could just appreciate the difference between lifted weights of twenty-nine and thirty ounces, could also just distinguish between weights of twenty-nine and thirty drams, approximately. He arrived at similar conclusions in the case of pressures applied to the skin, and in the case of short lines compared by the eye.

In more general terms, he concluded that the just appreciable difference between two objects depends on the ratio of that difference to the magnitude of the objects, not on

[1] See footnote to Chapter III.

the absolute difference between the magnitudes. This is Weber's law, which has since been found to hold for various other forms of stimuli besides those which Weber himself employed.

The law is but an exact formulation of everyday experience. In the stillness of night the ticks of a watch are loud, although inaudible amid the noise of a railway journey. A candle, carried into a room at twilight, makes a noticeable difference in its illumination, whereas at noon the effect is inappreciable.

The relation between the liminal increment Δi and the magnitude of the stimulus i depends upon the nature of the stimulus. For lifted weights it is as we shall see about one-thirtieth (exp. 119). For pressures on the finger-tip it has been found to be about one-twentieth, for brightness of light about one-hundredth, and for intensities of noise about one-third; two sounds of different loudness can just be distinguished as different, provided that the intensity of one is greater by about one-third than that of the other.

Limits of the Law.—The law is only obeyed where all disturbances due to imperfect sensory adaptation are eliminated. For example, the eye must be adapted to the particular brightness value of i which is chosen, before its differential threshold is investigated; otherwise the ratio $\frac{\Delta i}{i}$ varies for different values of i. Further, the law presupposes adequate practice on the part of the subject under investigation.

Weber's law only holds for moderate values of stimulus strength. If we can just detect a difference between weights of twenty-nine and thirty drams or ounces, we may yet be unable to distinguish between twenty-nine and thirty stones or grains; and similarly with very loud or weak sounds, or with very intense or weak degrees of brightness. Clearly, if the absolute value of the stimuli become sufficiently small,

a limiting point is reached at which we are determining no longer the differential but the absolute threshold.

The law has been found to hold for differences in the intensity of odours and of tones, in addition to the above-named stimuli. The law broadly holds wherever the physiological bases, *i.e.* the specific nervous energies, underlying the two experiences, differ merely in degree. On the other hand, it fails where the bases, or specific energies, differ in kind. For example, the smallest appreciable difference of pitch between two tones is constant throughout a considerable range of tones; a person who can just distinguish the tones of 200 and 200·75 vibrations from one another will just be able to distinguish the tones of 400 and 400·75 vibrations. Were Weber's law operative, a difference of 1·5 instead of 0·75 vibrations would be necessary in the latter case. But it is inoperative, as we are here dealing with two different kinds of specific nervous energy.

The Interrelation of Extensive and Intensive Changes.—From the standpoint of physiology, differences in spatial extent are not so far removed from differences in intensity as at first sight they appear to be. In the first place, a given nerve fibre, N_a, supplies not only an area *a* but also helps in supplying adjoining areas *b*, *c*, *d*; similarly a nerve fibre N_c supplies not only *c* but also the areas *b* and *d*, and in addition perhaps the areas *a* and *e*. So, when the areas *a*, *b*, *c*, *d*, *c* are simultaneously stimulated, the physiological effect on the fibre N_c is similar to a sufficiently intense stimulation of the area *c*. Secondly, in addition to this overlap at the periphery, neighbouring nerve fibres are often interconnected more centrally, so that adequate excitation of a nerve cell by a given nerve fibre may lead to overflow or irradiation of the impulse into other cells fed by other nerve fibres. For these reasons it is not surprising that Weber's law holds for short spatial extents.

Easily Appreciable Differences.—The principle involved in Weber's law holds not only for just appreciable, but also

for easily appreciable differences in stimulus magnitude. If a number of greys of different brightness be so chosen as to form a series of successive equidistant grades of brightness, then the ratio of the physical, *i.e.* photometric, intensities between any two consecutive greys is found to be approximately constant. Thus, if eight grey papers, *a, b, c, d, e, f, g, h*, have been chosen so that the difference between *c* and *b* appears equal to that between *b* and *a*, the difference between *d* and *c* appears equal to that between *c* and *b*, and so on; then if i_a, i_b, i_c, i_d . . . represent the physical or luminosity values of these greys, the ratios $\frac{i_b}{i_a}$, $\frac{i_c}{i_b}$, $\frac{i_d}{i_c}$, $\frac{i_e}{i_d}$, $\frac{i_f}{i_e}$, . . . will be found to be approximately equal. Astronomers have obtained like results in classifying the stars according to apparently equal differences of magnitude. Consequently, we can now express Weber's law in more general terms: like experiences of stimulus difference are dependent on like relations between the magnitude of the difference and the absolute magnitude of the stimulus.

Fechner's Law.—After having more exactly verified Weber's law and emphasised its importance, Fechner proceeded to make deductions from it, by the help of various lines of mathematical reasoning; one of which is here given. He argued that if s_1, s_2, represent two sensations produced by the stimuli i_1 and i_2, experiment justified him in concluding that, so long as $\frac{i_1}{i_2}$ remains constant, $s_1 - s_2$ must be constant; in other words, that

$$s_1 - s_2 = f\left(\frac{i_1}{i_2}\right) \quad (1)$$

or $$s_2 - s_1 = f\left(\frac{i_2}{i_1}\right) \quad (2)$$

where f is the usual sign of functional dependence and implies here that the difference between two sensations is dependent on the ratio of the magnitudes of the

stimuli. Now suppose that in (1) $i_2 = i_0$, being a strength of stimulus which is too weak to produce a sensation. Then $s_2 = o$ and

$$s_1 = f\left(\frac{i_1}{i_0}\right) \quad (3)$$

Or supposing that in (2) $i_1 = i_0$, then $s_1 = o$, and

$$s_2 = f\left(\frac{i_2}{i_0}\right) \quad (4)$$

From (3) and (4) $s_1 - s_2 = f\left(\frac{i_1}{i_0}\right) - f\left(\frac{i_2}{i_0}\right)$

Hence from (1) $f\left(\frac{i_1}{i_2}\right) = f\left(\frac{i_1}{i_0}\right) - f\left(\frac{i_2}{i_0}\right)$,

or $f\left(\frac{i_1}{i_0}\right) = f\left(\frac{i_1}{i_2}\right) + f\left(\frac{i_2}{i_0}\right)$,

but $f\left(\frac{i_1}{i_0}\right)$ may be expressed as $f\left(\frac{i_1}{i_2} \times \frac{i_2}{i_0}\right)$.

$$\therefore \; f\left(\frac{i_1}{i_2} \times \frac{i_2}{i_0}\right) = f\left(\frac{i_1}{i_2}\right) + f\left(\frac{i_2}{i_0}\right).$$

This is an equation of the form

$$f(xy) = f(x) + f(y),$$

a general solution of which is only possible by putting

$$f(xy) = k \log xy,$$

$$f(x) = k \log x,$$

and $f(y) = k \log y$,

where k is a constant.

Therefore, $f\left(\frac{i_1}{i_2}\right) = k \log \frac{i_1}{i_2}$

and (1) becomes

$$s_1 - s_2 = k \log \frac{i_1}{i_2}.$$

Let us now suppose s_2 to be a just inappreciable sensation,

and the necessary strength of the corresponding stimulus i_2 to be equal to unity.

Then $$s_1 = k \log i\text{; or generally,}$$
$$S = K \log I.$$

This conclusion, that the sensation is proportional in strength to the logarithm of the stimulus, constitutes Fechner's law.

[*A Critical Examination of Fechner's Law.*—It is interesting to follow the results of other substitutions in the equation $s_1 - s_2 = k \log \frac{i_1}{i_2}$. Supposing the stimuli to be of equal strength, then $i_1 = i_2$ and $k \log \frac{i_1}{i_2}$ consequently becomes zero. That is to say, $s_1 = s_2$, as is truly the case.

On the other hand, supposing that i_1 is ever so slightly different from i_2, then s_1 and s_2 must immediately differ. But this is quite contrary to actual experience. The expression $s_1 - s_2$ remains zero until $\frac{i_1}{i_2}$ has exceeded a certain liminal value.

Again when, in the equation $S = K \log I$, I is unit strength, S becomes zero as it should by hypothesis. But how are we to interpret the increasing negative values of S, which are given as the strength of I diminishes from unity to zero?

Endeavours have been made to escape from the former, at least, of these difficulties, by distinguishing between the physiological excitation on the one hand, and the experience of sensation on the other: between the activity of the lower parts of the nervous system, which form the sensory apparatus, and the activity of the higher cerebral centres, whereby we become conscious of sensations and sensation differences.

We must admit that, when a subliminal stimulus or a subliminal stimulus difference produces no change in consciousness, it may nevertheless have a non-conscious, solely

physiological, action of some kind. And it is quite conceivable that it is the relation between this purely physiological action and the strength of the stimulus that Fechner's law expresses. But Fechner maintained that the logarithmic relation, implied in his law, lay, not between these, but between the physiological action (or psycho-physical activity, as he termed it) and the mental experience of the sensation; he believed that the law expressed the relation between "psycho-physical" and "mental" process.

Within the limits of an elementary treatise, it is impossible to examine Fechner's other views in adequate detail. But it should be noticed that he regarded a sensation as the sum of a number of just appreciable unit increments of sensation, or as the sum of a number of just appreciable unit sensation differences. He maintained that the change of sensation, obtained by adding one ounce to a weight of twenty-nine ounces, was absolutely, as well as relatively, the same as that obtained by adding one dram to a weight of twenty-nine drams. Of course, were this so, an ounce and a dram should produce an equal sensation.

Fechner's error lay in his rigid, unreflecting application of mathematics to psychological data. By the equation $s_1 - s_2 = f\left(\frac{i_1}{i_2}\right)$ we mean that our experience of difference between two stimuli is dependent on the ratio of the magnitudes of the stimuli. Experiment teaches us that it holds only for moderate values of i_1 and i_2. Hence when i_1 is so small ($=i_0$) that it fails altogether to evoke any experience at all, it is quite unjustifiable to conclude that $s_1 = f\left(\frac{i_1}{i_0}\right)$ or similarly that $s_2 = f\left(\frac{i_2}{i_0}\right)$.

Moreover, Fechner assumed that the expression $s_1 - s_2$ stands for a difference between two experiences, whereas it denotes an "experience of difference." The experience that two stimuli are identical or different as strictly *sui*

generis as the experience of a stimulus itself. Indeed, we may go still further, and say that our judgment, that an experience of one difference is identical with or different from another, is as single and undivided an experience as our judgment, that an experience of one stimulus is identical with or different from another. In each instance, what is in consciousness is an experience of identity or of difference. The threshold for the experience of a difference demands precisely the same psychological treatment as is accorded to the threshold for the experience of a stimulus.

For this reason we are not warranted in treating the expression $s_1 - s_2$ as if it expressed merely a difference between two experiences, and in adding to it, subtracting from it, or otherwise manipulating it as if two separate psychic entities were present. The expression $s_1 - s_2$ represents a single state of consciousness, the experience of a difference. It admits neither of dissection nor of mathematical treatment.

This distinction which we have drawn between a difference of experiences and an experience of a difference is well brought out, when we consider the case of two stimuli which are not sufficiently different to give rise to an experience of difference. Because we have here a subliminal experience of difference, it would be wrong to conclude that s_1 and s_2, the psychic effects of the two stimuli, are in themselves equal. For if s_1 and s_2 were identical in the case of two subliminally different stimuli i_1 and i_2, and if similarly s_2 and s_3 were identical in the case of two subliminary stimuli, i_2 and i_3; then, in the case of the two stimuli i_1 and i_3, s_1 and s_3 should be identical, whereas in fact there may be a very distinct experience of difference.

Lastly, even if s_1 were equal to $f\left(\frac{i_1}{i_0}\right)$ and s_2 to $f\left(\frac{i_2}{i_0}\right)$, Fechner's conclusions that $s_1 - s_2$ is equal to $f\left(\frac{i_1}{i_0}\right) - f\left(\frac{i_2}{i_0}\right)$ would be psychologically unjustifiable. A moment's

reflection will show that we cannot manipulate our sensations in this way. For instance, we cannot say that we double the strength of a sensation when we superimpose two sensations of equal strength upon one another.]

[*Immeasurability of Sensation.*—Indeed we are powerless to measure sensation strengths at all. We can say that one sensation is equal to, greater or less than, another sensation produced by a stimulus of like or different magnitude, but we cannot say how much the one is greater or less than the other. The cannon roar is louder than the crack of a pistol, but we cannot express the former experience in terms of the latter.

A quantity is only measurable when it is capable of division into equal unit parts. Temporal and spatial experiences are thus divisible. We can measure the intensity of a visual or an auditory stimulus by the extent or amplitude of the vibration; we can measure a given weight, a given size, or a given time interval by the number of molar, spatial, or temporal units which it contains. Sensations, however, *quâ* sensations, cannot thus be measured. They can be arranged in a graded series, increasing or decreasing in intensity, but we cannot divide a sensation into equal unit sensations. All that we can say is that so many pistols simultaneously fired would produce the sensation of a given cannon roar, that so many candles simultaneously lighted would produce the sensation of a given arc light, that so many ounce weights simultaneously lifted would produce the sensation of a given pound weight.

But to state the conditions under which a given sensation may result is not equivalent to measuring the strength of a sensation itself; it is not equivalent to stating that one sensation is a hundredfold or a hundredth part of another or unit sensation. From the standpoint of experience such sensations have no numerical relation to one another. Consequently, the determination of their magnitude by reference to the strengths or extents of the corresponding

stimuli becomes meaningless. In other words, Fechner's law has no psychological foundation.]

The Basis of Weber's Law.—We have seen that Fechner believed that Weber's law was an expression of the relation between the physiological excitation due to sensory stimulation, on the one hand, and its affection of consciousness on the other. But other interpretations of the law have been offered, which it is now our duty to examine.

Wundt has suggested that the process of "apperception" is the cause of Weber's law. He supposes that a given stimulus or stimulus difference can only be adequately experienced after the more elementary psychical reactions to which it gives rise have been subject to apperception, by being related to other experiences. But if it be in this higher "faculty" of apperceptive comparison that Weber's law originates, we may well ask why the law does not hold in the case of *all* judgments of difference,—for example, in the case of the estimation of the smallest appreciable differences of pitch?

It is far more probable that the law is a general expression of the relation of protoplasmic activity to the strength of the exciting stimulus. For if the extent of negative variation of the current be observed in a stimulated afferent nerve, and if it may be regarded as evidence of the strength of the nervous impulse, we appear to be face to face with Weber's law, when the frog's eye is stimulated by lights of different intensity, or when the frog's skin is stimulated by weights falling on it with different momenta.

Ebbinghaus suggests that the law may be a result of the difference in degree of stability between the protoplasmic molecules which are broken down by the stimulus. The more unstable molecules are easily decomposed by relatively feeble stimuli. Thus, when two weak stimuli follow one another, a small difference between them is sufficient to produce a difference in the number of molecules upon which they have acted. On the other hand, when two strong

stimuli follow one another, the less stable molecules are decomposed by the first strong stimulus, and consequently a greater difference between the two stimuli is necessary for the one stimulus to succeed in breaking down a greater or less number of molecules than the other. If the sensation difference depend on such differences of molecular decomposition, it is held that we have a rough diagrammatic conception of the mode of action of Weber's law.

It has also been suggested that the law is due to the extent of irradiation of the given impulse to neighbouring ganglion cells; the area of irradiation being relatively less, the greater the strength of the stimulus.

The Completeness of the Judgment.—So far we have confined our attention to the nature and significance of Weber's law, as if our judgments of identity and of difference were due solely to its operation. The remaining pages of this chapter will show that this is very far from being the case.

The threshold of difference is dependent on the completeness of the judgment that is required. The threshold is generally lower when the subject is merely asked whether or not a difference exists than when he is asked to determine the direction of that difference.

[*The Mode of Presentation.*—The delicacy of discrimination also depends upon whether the two stimuli are presented simultaneously or successively. The threshold is usually lower for successive than for simultaneous presentations. For example, smaller differences of weight can be discriminated when the objects are lifted successively than when they are lifted simultaneously. Moreover, when they are successively lifted by the same hand, the threshold is lower than when they are lifted by different hands.

The appreciation of difference also depends on the suddenness with which the change is made from the one stimulus to the other. The differential threshold may be enormously raised, if only the increase or decrease of the stimulus proceed with adequate slowness and regularity.

On the other hand, beyond certain limits, a too rapid change of a continuously varying stimulus causes a rise in the differential threshold.]

[*Practice.*—Practice is of considerable influence in lowering the differential threshold. Its effects are confined within surprisingly narrow limits to the particular exercise performed. Thus the practice, acquired in discriminating successive sounds of nearly identical pitch, is largely lost when the subject is confronted with sounds of different timbre produced by another instrument, or when one region of a scale is exchanged for another. Similarly, persons who are extremely sensitive to differences of timbre (*e.g.* to differences of voice) may have very obtuse powers of discrimination in regard to differences of pitch. A threshold which practice has lowered on one side of the body is almost correspondingly lowered on the symmetrically opposite side of the body.]

The Time Error.—It has been found that when pairs of heavy weights are lifted, the second of any pair tends to be judged heavier than the first. This is Fechner's negative time error. It is said to be increased by slow lifting and by fatigue, and to be decreased when the weights are light. With light weights the time error may be positive. We may explain the positive time error by supposing that the nervous impulses, involved in the first lift, favourably influence, either by facilitation or by incitation, the strength of the next nervous impulses corresponding to the second lift. In equating long lines and short lines, the time error is found to change in a sense opposite to that which holds for lifting weights. But individual variations, and variations of the same individual under different conditions, show that the causes that influence the time error are far too complex to be explained at present (exps. 120, 121).

The Time Interval.—The recognition of identity or difference between two stimuli is much affected by the interval of time which elapses between their presentation. When the

individual has had adequate practice, and when the interval between the two stimuli is sufficiently short, he tends to give the judgment of difference or identity immediately and unreflectingly. Introspection shows that under these conditions he often makes no true comparison between them. He does not hold the one stimulus in his mind beside the other, passing from the first to the second and from the second back to the first, weighing, so to speak, the difference between them. On the contrary, his decision is immediate, and involves no comparison. It is as if the one presentation produced one change in the total mental attitude or disposition of the subject, while the other created another change, and as if the judgment of identity or difference were the unreflecting result of sameness or want of sameness between these two reactions. In such situation the judgment rests on a vague state remote from clear cognition,—on what we loosely, perhaps wrongly, term a "feeling" of familiarity or unfamiliarity (page 150).

With increasing interval of time between the two presentations, especially in the absence of practice, memory images of the two stimuli may become an important, if not an essential, factor in the judgments of identity or difference. The vividness and accuracy with which some kind of memory image of the first stimulus can be evoked upon, or just after, the presentation of the second stimulus, may materially affect the correctness of the subject's answers (page 149).

The Absolute Impression.—A further complication is especially liable to arise, when, as so often happens during a series of experiments, one of the stimuli is constant, or when all the stimuli are taken from a narrow region of their possible range. The subject comes to form an "absolute impression" of the given stimuli. His judgments no longer rest simply on the comparison of one stimulus with another, but they are influenced by the absolute impression conveyed by one or other or both stimuli; just as in everyday life we speak of to-day as bright or dull, or of a given sound as loud

or faint, without going through the process of comparing it with other days or with other sounds.

The influence of the absolute impression comes prominently to the fore in such an investigation as the following, in which the constant method (the method of right and wrong cases) is applied to the discrimination between a standard and a variable weight placed simultaneously before the subject and successively lifted by his same hand. The research is worth a detailed description for the light that it throws on the value of a psychological experiment, methodically conducted by the experimenter and adequately assisted by introspection on the part of the subject (exp. 121).

We shall call the standard weight S and one of the variable weights $S-d$. Outwardly, the two weights are precisely alike, and the conditions of lifting each weight are as nearly as possible constant; a metronome and a horizontal piece of string regulating the rate and the height of lifting successive weights. Then for the two weights S and $S-d$, there are the following four possible relations of the two lifts in space and time:—

a_1, standard weight lifted first and placed to the right of the variable,

a_2, „ „ second and placed to the right of the variable,

a_3, „ „ first and placed to the left of the variable,

a_4, „ „ second and placed to the left of the variable.

Throughout every series of investigations we shall employ not only the pair of weights (S and $S-d$), for which we have used the letter a, but also the pair of weights (S and $S+d$), which we shall denote by the letter b. This latter pair may be lifted in any one of the temporal or spatial relations b_1, b_2, b_3, b_4, corresponding to a_1, a_2, a_3, a_4 of the former pair. Thus there are eight separate heads under which the percentage of right and wrong answers may be

classified, according to the different relations of the standard and variable weights. We shall use the letters a_1-a_4, b_1-b_4, briefly to express the different percentages of right answers obtained under these eight heads. The subject is directed to return his answers in terms of the second presentation, *e.g.* "second lighter," "second heavier," "no difference."

Excepting the slight effect due to the operation of Weber's law, we should expect that $\Sigma a = \Sigma b$, where $\Sigma a = a_1 + a_2 + a_3 + a_4$, and $\Sigma b = b_1 + b_2 + b_3 + b_4$.

With the same limitations, we should also expect that $a_1 = b_4$; in other words, that the percentage of right answers, when the heavier weight is lifted first and lies to the right of the second lifted weight, should be the same for S and $S-d$ as it is for S and $S+d$. Similarly, we should expect that $a_2 = b_3$, $a_3 = b_2$, and $a_4 = b_1$.

Instead of this, we find from experiment that as a rule $a_1 > b_4$, and that $a_2 < b_3$, $a_3 > b_2$, $a_4 < b_1$. We conclude that the percentage of right answers is greater when the standard precedes than when it follows the variable. This has been called the "general tendency of judgment."

Further, the equation $\Sigma a = \Sigma b$ usually does not hold. Some individuals return a sensibly greater percentage of right answers when the standard is heavier than the variable ($\Sigma a > \Sigma b$), while others succeed better when the standard is lighter than the variable ($\Sigma a < \Sigma b$). The former are spoken of as belonging to the positive type, the latter to the negative type, while those for whom $\Sigma a = \Sigma b$ belong to the indifferent type. We may call this condition the "typic tendency of judgment."

The effects of time and space order may be also investigated. Summing a_1 and a_3, we have the effect of the standard lifted first; summing a_2 and a_4, we have the effect of the standard lifted second. Let us call the percentage for these two time orders A_1 and A_2, and those for the corresponding two time orders of the b series B_1 and B_2.

Then, in the absence of other influences, we should expect the values A_1, B_1, A_2, B_2 to be equal. If A_1 is greater or less than A_2, and B_1 is similarly less or greater than B_2, we must attribute their difference to the time error, and estimate it in the manner already indicated. The time error (page 266) is conveniently termed positive or negative according as the influence of the time order causes the first presentation to appear greater or less than the second. The space error may be similarly determined (page 203).

Martin and Müller, to whom we owe this research, have applied their investigations to so many individuals, and have extended their experiments over so long a time, that the utmost reliance can be placed on the outcome of their accumulated data. They suggest that the general tendency of judgment ($a_1 > b_4$, $a_2 < b_3$, $a_3 > b_2$, $a_4 > b_1$) and the typic tendency of judgment ($\Sigma a_1 \gtreqless \Sigma b$) receive a ready explanation, if the influence of the "absolute impression" be taken into consideration. When, during a series of continuous experiments, one and the same standard weight is used, we come to judge of the lifted weight as we judge of weights in ordinary life, *e.g.* the weight of a box as absolutely heavy, or the weight of a baby as absolutely light; and our verdict comes to be much influenced by this absolute impression. Martin and Müller conclude that this absolute impression of heaviness or lightness enters more frequently in the case of weights which are heavier or lighter than the standard weight than in the case of the standard weight itself; and it would seem that the greater the difference between the variable and the standard, the more evident is the action of the absolute impression. While admitting that in some cases our judgment of the difference between two lifted weights depends on actual comparison between them, they insist that we often form an absolute impression of one of the weights, so that, if the first or second lifted weight give

the impression of absolute lightness or heaviness, the other weight tends to be pronounced the heavier or the lighter.

Now the absolute impression of the first lifted weight has obviously less effect on the judgment than the absolute impression of the second lifted weight, since it can only influence the judgment by being remembered. If we add to this the already mentioned condition that the variable awakens an absolute impression more often than the standard, we account for those results which Martin and Müller describe as the general tendency of judgment.

The positive, negative, and indifferent types of judgment appear to be chiefly dependent on the strength of the subjects. Most men, being powerful lifters, conform to the positive type; that is to say, they return more right answers when the variable is less than when it is greater than the standard. Most women, on the other hand, seem to belong to the negative type. Occasionally the type of a subject changes during a long continued course of experiment, passing through a stage of indifference ($\Sigma a = \Sigma b$) from one type to the other. The onset of fatigue, or the increase in weight of the standard weight, leads to an increase of negativity in a subject of the negative type, and to a decrease of positivity, or even to reversal, in a subject of the positive type.

According to Martin and Müller, these individual differences and changes of type are the natural results of the individual differences and changes in absolute impression. A person who with given weights forms the absolute impression of lightness, will appreciate a weight of increased lightness more readily than one of increased heaviness; whereas a more weakly person, who with the same weights forms the absolute impression of heaviness, will appreciate more readily a weight of increased heaviness than one of increased lightness. Such an explanation receives some confirmation from observation of the ways in which different subjects express their replies, during the course of a special

series of experiments in which the subject's direction of judgment is left entirely free (page 216). One subject, for example, who is manifestly of the positive type, is found always to give his answers in terms of lightness, *e.g.* "right weight lighter," "left weight lighter." The contrary replies occur in subjects of the negative type, whereas in a subject of the indifferent, his answers are given in various directions.

Side Comparisons.—The experimental data and the introspective records will also show the occasional influence of "side comparisons." That is to say, the subject's judgment is influenced by one or other of the stimuli of the preceding pair. If, for example, the first of a given pair of stimuli appear smaller than a preceding stimulus, it is apt thereby to appear smaller than the second stimulus with which it has to be compared.

[*The Coherence of Stimuli.*—We are now in a position to appreciate the vast number of different influences which tend to obscure and to counteract the play of Weber's law. No wonder, then, that the latter is especially apt to be over-ridden in the determination of equal-appearing differences (page 215). Indeed, it is sometimes found that the stimulus *b*, so far from being the geometrical mean between *a* and *c*, approaches or even exceeds the arithmetical mean, when the subject judges that the difference between *a* and *b* is equal to that between *b* and *c*. This divergence from Weber's law probably occurs when the presentations corresponding to *a* and *b* or to *c* and *d* are incapable of being apprehended as a single experience. So long as the subject is engaged in equating two single experiences, the law is approximately obeyed. For various reasons, however, *a* and *b*, or *b* and *c*, may not "cohere" so as to form such a single experience. If, for instance, *a* be very bright or very heavy, the attention is apt to be directed specifically towards it, an absolute impression of brightness or heaviness results, and, in consequence, *a* and *b* never blend sufficiently, but remain

more or less isolated from one another (exp. 122). A similar explanation may account for the fact that, while (under favourable conditions) Weber's law holds good for the differential threshold of intervals of time, it does not hold good when a time interval is sought which lies midway in length between two other time intervals.]

BIBLIOGRAPHY.

E. H. Weber, "Der Tastsinn u. d. Gemeingefühl," *Wagner's Handwörterbuch d. Physiol.*, Braunschweig, 1846, iii. 2te Abth., 481. G. T. Fechner, *Elemente d. Psychophysik*, Leipzig, 1860. E. Hering, "Zur Lehre v. d. Beziehung zw. Leib u. Seele," *Sitzungsber. Wiener Akad. d. Wiss.*, Math.-nat. Cl., 1875, lxxii. Abth. 3, 310. H. Ebbinghaus, "Über d. Grund d. Abweichungen v. d. Weber'schen Gesetz bei Lichtempfindungen," *Arch. f. d. ges. Physiol.*, 1889, xlv. 113. A. D. Waller, "Points relating to the Weber-Fechner Law," *Brain*, 1895, xviii. 200. L. J. Martin u. G. E. Müller, *Zur Analyse d. Unterschiedsempfindlichkeit*, Leipzig, 1899. F. Angell and G. Harwood, "Discrimination of Clangs for Different Intervals of Time," *Amer. Journ. of Psychol.*, 1899, xi. 67; 1900, xii. 58. W. Ament, "Über d. Verhältniss d. ebenmerklichen zu d. übermerklichen Unterschieden bei Licht u. Schallintensitäten," *Philosoph. Stud.*, 1900, xvi. 135. F. Angell, "Discriminations of Clangs for Different Intervals of Time," *Amer. Journ. of Psychol.*, 1901, xii.; "Discriminations of Shades of Grey for Different Intervals of Time," *Philosoph. Stud.*, 1902, xix. 1. W. Wundt, *Grundzüge d. physiol. Psychol.*, Leipzig, 1902, i. 493. J. Fröbes, "Ein Beitrag über die sogenannten Vergleichungen übermerklicher Empfindungsunterschiede," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1904, xxxvi. 241, 344. E. B. Titchener, *Experimental Psychology*, New York, 1905, ii. introduction to pts. 1, 2. A. Aliotta, *La Misura in Psicologia Sperimentale*, Firenze, 1905.

CHAPTER XX

ON BINOCULAR EXPERIENCE[1]

Binocular Combination.—The images of two like objects, received separately by the two retinæ, may combine to produce vision of a single object. Such binocular combination may almost as easily be produced without the aid of the stereoscope as with it (exps. 123, 124).

Corresponding and Disparate Retinal Points.—Those twin points, one on one retina, the other on the other, which ascribe the same localisation to an object in the field of binocular vision, are termed " corresponding " points. When the rays from an object fall on corresponding points of the retinæ, the object is seen as a single object. When the rays fall on non-corresponding, or, as they are termed, on " disparate " points, either single vision or " diplopia " (*i.e.* double vision) results, according to circumstances into which we shall presently (page 276) enter.

Uncrossed and Crossed Disparation. — When a single object is doubled in binocular vision (exp. 125), the image received by each eye appears to be on the same side as, or on the side opposite to, the eye that receives it, according as the object lies farther, or nearer, than the point of fixation. These conditions of " uncrossed " and " crossed " images are known respectively as uncrossed and crossed " disparation."

The accompanying diagram (fig. 9) more fully explains their causation. Here F is the fixation point, rays from which fall on the corresponding retinal points f_1, f_2. O is

[1] See footnote to Chapter III.

an object, lying beyond the fixation point. Rays from it fall on the markedly disparate retinal points o_1, o_2. In consequence, diplopia occurs, the two images of the object o appearing as O' and O''. When the object lies nearer than the fixation point, as at X, the well-marked disparation of the retinal points x_1 and x_2 again produces diplopia, but in this case the disparation is crossed. The images X' and X'' are treated as objects situated on the side opposite to the eye which receives them, whereas the images O' and O'' are treated as objects situated on the same side as that of the eye which receives them.

Covering Points.—Corresponding points have been sometimes termed "identical" or "covering" points. But it would be a mistake to suppose that, if the two retinæ were superimposed, with the right and left foveæ and the horizontal and vertical axes overlying, the corresponding points would then accurately coincide. Experiments have shown that between the vertical meridians of the two retinæ a "physiological incongruence" exists. When the eyes are in the "primary" position, *i.e.* when they are horizontally regarding an infinitely distant object, the vertical meridians of corresponding retinal points diverge upwards to form an angle of about 2°. A slighter incongruence may also occur in the horizontal meridian.

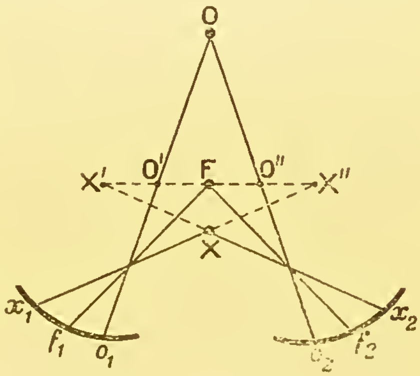

Fig. 9.

Neglected Diplopia.—It is clear that at no moment in our ordinary life can stimulation of the two retinæ be limited to corresponding points. In other words, the single images of certain objects, arising from the correspondence of bi-retinal points, must always be accompanied by the double images of other objects, arising from the disparation

of other points simultaneously excited. But we neglect this constant diplopia, just as we neglect the blindness of each blind spot (exp. 116) or the colour blindness of the peripheral retina (exp. 52).

The Horopter.—The "horopter" is a line or surface in the field of vision, whose constituent points fall on corresponding retinal points in a given position of the eyes. The forms of the horopter have been determined, both by mathematical and by empirical methods, for different positions of the eye.

The Cyclopean Eye.—Under ordinary circumstances we localise binocularly-seen objects in a direction midway between the two eyes (exps. 126, 127), and in uniocular vision our localisation rests usually on this basis. In other words, the two eyes, whether used separately or combined, tend to function in regard to localisation as a single median "cyclopean" eye. This tendency has to be suppressed in shooting and in other uniocular exercises.

Depth and Disparation.—Provided that the disparation is relatively slight, the simultaneous stimulation of non-corresponding points on the two retinæ still permits of single vision. The degree of disparation that is consistent with the absence of diplopia varies to some extent with practice. But although the image of the point (or object) is not doubled, its relative position in space becomes changed. If the disparation be due to excessive distance of the retinal points of stimulation from one another, the object appears to be nearer, and if it be due to insufficient distance, the object appears to lie farther, than the position which is ascribed to the single image obtained from truly corresponding points.

Fig. 9, if now regarded in a different sense, is useful in making this relation clearer. Let X' and X'' represent two objects, the rays from which fall on the now moderately disparate points x_1 and x_2. So long as the disparation is not excessive, binocular combination is still possible, a single

object is seen and it is referred to X, which lies nearer than the fixation point F. On the other hand, if O' and O'' be the two objects, and if the disparation is due to insufficient distance of the twin retinal points o_1 and o_2, binocular combination is again possible, provided that the disparation is not too great; but the single object is referred to O, a point more distant than the fixation point (exp. 128).

Thus the apparent distance of objects (farther or nearer than the fixation point) is related to the nature and degree of retinal disparation. According to Hering, retinal disparation is the innate physiological datum on which our experiences of depth, and of distance relative to the fixation point, are directly based.

Depth and Eye Movements.—On the other hand, it has been urged that such experiences depend not directly on retinal disparation, but on the kinæsthetic sensations arising from movements of each eyeball and lens, *i.e.* from changes in binocular fixation and accommodation, which are provoked to correct the diplopia and to obtain well-defined images respectively. How far these muscular sensations play a part in the development of distance perception is uncertain; but the following considerations show that they are by no means essential, so far, at least, as concerns adult experience.

The distances of falling objects from the fixation point may be compared when they are visible to the eyes for so short a time as to preclude orbital movement (exp. 129). The characteristic depth of stereoscopic pictures persists when the stereoscope is only momentarily illuminated—again precluding movement. Stereoscopic effects may be obtained by combining the after-images of stereoscopic pictures, either when the latter have been regarded simultaneously or even after they have been regarded successively.

On the other hand, in favour of the influence of kinæsthetic sensations upon the perception of distance, the

following experiment has been adduced. If one of two vertical black threads, both seen before a uniform white ground by one eye, be made to approach the observer, he will often be able to tell whether the one is advancing or is at a different distance from the other, although the size of the retinal image is practically unchanged. This ability has been attributed to sensations arising from accommodation. It is, however, difficult completely to exclude all other factors (difference of light and shade, for instance, and even minute changes in size) which may influence our perception of distance. Moreover, in a similar but more delicate experiment, wherein the subject uniocularly regards the border line that vertically divides two surfaces, one black, the other white, from one another, he is found incapable of judging the distance of the movable black screen from him, or of telling whether it is being moved to or from the stationary white background.

It is certain that the muscular sensations of the eyeballs afford us scant knowledge of the position of the eyes in darkness. When the finger is held up in the dark and attempts are made to turn the eyes to it, considerable inaccuracies in convergence are found to occur. Or if the eyes be fixed on a bright spot in an otherwise dark room, and fixation be as accurately as possible maintained after extinction of that light, the eyeballs gradually wander without the subject being aware of their movement. Careful observation shows that the accurate preservation of fixation for brief periods even in daylight is impossible; such errors being, of course, negligible when compared with those which involuntarily occur in the absence of light. These considerations make it additionally difficult to accept the view that kinæsthetic sensations of orbital origin are of fundamental importance in adults for the perception of the third dimension.

On the other hand, it would be rash to assert that orbital and ciliary muscle sensations are, always and wholly, with-

out influence in this direction. They are conceivably of considerable importance in infancy, when they may aid in the elaboration of the innate system of corresponding and disparate points and of retinal local signs, and thus help to complete the meaning which correspondence and disparation come to possess.

It is noteworthy that squinters, in whom, of course, the normal congenital relation between corresponding points is utterly overthrown, come either to neglect the visual experiences of the squinting eye, or to elaborate a totally new system of relations between pairs of points in the two retinæ. By the latter procedure they acquire single vision by binocular combination, although they never altogether lose the congenital system of interocular relationship. At present we are ignorant whether or not kinæsthetic sensations play any part in the construction of this second system. It is also uncertain whether those persons who rely solely on uniocular vision depend for their appreciation of depth on other than the "psychological" factors to which we have now to refer.

Depth and Psychological Factors.—Distances can be still discriminated, even when the objects lie so far away (say, beyond 20 metres) that any differences due to retinal disparation or kinæsthesis must be negligible. We are then entirely dependent on inference. We estimate such distances or depths by differences in distinctness, in size, or in light and shade. The illusions of distance, which occur in exceptionally clear or foggy weather, show to what an extent we are habitually dependent on these "psychological" factors. Their importance is further instanced by the observation that the stereoscopic effects of a painting are far more striking in uniocular than in binocular vision. The two eyes, with their usual accuracy, insist that the canvas is flat; the effects of size, colour, light and shade are more effective in suggesting relief when the painting is viewed by a single eye.

Binocular Rivalry. — When corresponding points are stimulated by unlike stimuli, either combination or rivalry results. Coloured squares of equal size and brightness may be combined without difficulty. The more the two presentations differ in contour or in brightness, or the more they are incongruous in general meaning, the more impossible becomes binocular combination. Instead of combining, the two impressions alternate, sometimes one, sometimes the other, occupying the field of consciousness. The field can be to a great extent limited to one or other eye by the control of attention, or by the relative intensity or insistence of the sensations, either retinal or muscular, derived from the two eyes. One of the images can be completely suppressed by practice (exp. 130).

[The effect of combining black and white fields binocularly is to produce a varying shade of grey which has a metallic lustre (exp. 130). The lustre of rough surfaces in uniocular vision is probably due to similar differences in the intensity of stimulation of neighbouring retinal points, owing to the irregular reflection of light from such surfaces. Thus the phenomenon would be an instance of a pair of neighbouring points on the single retina being able to evoke the same experience as a pair of slightly disparate (or corresponding) points on the two retinæ.]

[*Uniocular Relief.*—If this were so, we might expect uniocular stereoscopy to result when the image of an object is so thrown on the single retina as to stimulate in rapid alternation (i.) given points (a_1, b_1, c_1 . . .) and (ii.) neighbouring points (a_2, b_2, c_2 . . .) of the same retina corresponding to points on the opposite retina which are slightly disparate to the points a_1, b_1, c_1. . . . We have experimental evidence that under such conditions uniocular relief does actually occur. Its occurrence promises to throw much light on the physiological and anatomical basis of our perception of depth. It may form an important factor in the spatial perception of one-eyed individuals.

A very different form of uniocular relief occurs when blue and red letters are uniocularly regarded on a black ground. The letters of one colour appear to be nearer or farther than those of the other colour, according to the individual and the direction from which he regards them. Such colour relief has been attributed to individual differences in the eccentric position of the pupil with respect to the visual axis, and in the position of the coloured "circles of diffusion" on the retina which differ according as the eye is accommodated for one colour or for the other. The borders of the letters appear light or dark, and these apparent differences of shading, varying with the nasal or temporal eccentricity of the pupil and with the direction of regard, suggest relief.]

Binocular Contrast.—Under certain conditions, a coloured stimulus applied to one eye can be made to evoke the contrast colour sensation in the opposite eye (exps. 131, 132, 133). The close resemblance of binocular to uniocular contrast compels us to suppose either that colour sensations are of more central origin than is commonly believed, or that a direct nervous connection exists between the two retinæ whereby stimulation of one eye leads to retinal changes in the opposite eye. Such nervous connection has been definitely demonstrated. Further, we know that movement of the cones, produced in one eye, leads to cone movement in the opposite eye. But this reaction is too slow to explain the immediacy of binocular contrast. It has been suggested that the electrical variation in the two eyes, which is known to occur after uniocular stimulation, may be the physiological basis of binocular contrast.

[*Binocular Flicker and Brightness.*—When two flickering discs of light, precisely similar in all respects, are thrown on corresponding areas of the two retinæ, and the two retinal images are binocularly combined, it is found that the rate of intermittence necessary to extinguish flicker in the

binocular image is almost exactly the same as the rate necessary to extinguish flicker, when only one of the discs is seen, uniocularly.

When two such, binocularly combined flickering discs, are arranged so that the component dark and bright phases of each flicker synchronise in the two eyes, and are compared with two other flickering discs, similarly combined but arranged so that the phases alternate,—the bright phases of the flicker in one eye being synchronous with the dark phases in the other,—the rate of rotation at which flicker is extinguished is approximately the same for the two images arising by combination of the two pairs. There appears to be practically no interference or combination between corresponding points of the two retinæ under these conditions, however different be the phases of reaction of these points at any moment. Moreover, when flicker is extinguished, there is not the slightest difference in brightness between the combined images. That is to say, no trace exists of a Talbot-Plateau law (page 86) applicable to an imaginary single retina, the functional composite of the two retinæ.

On the other hand, when a steady flickerless image is received on one retina, and a flickering image is simultaneously received on the corresponding area of the other retina, the flickering of the latter is very distinctly damped, and the extent of damping seems to remain constant throughout a considerable range of variation in the brightness of the flickerless image.

It would therefore appear that, while there is practically no binocular interaction between two flickering images binocularly combined, there is a marked interaction when one of the eyes receives a steady, in place of a flickering, light stimulus. This effect of a steady upon a flickering image appears comparable to the interaction of two uniocular steady images, to which we shall refer immediately. But we have yet to explain why a steady image is able, while a

flickering image is unable, to affect the image of the corresponding area of the other eye.

It might be thought that a certain stage in the elaboration of the results of retinal stimulation must be reached before such stimulation can influence experiences derived from the other eye. Yet, from the psychological standpoint, a flickering light is as elaborate a conscious state as a steady light. Moreover, on the physiological side, it is difficult to conceive a mechanism which shall at once account for the facts of retinal correspondence, cyclopean vision, cortical hemianopia and conjugate orbital movements, on the one hand, and for the recently discovered facts that we have just been describing on the other. Certainly the simple diagrams of the bi-retinal relation which have hitherto contented us are now quite inadequate. They may account for all motor reflexes, but they cannot account for all binocular conscious processes.]

The brightness of the combined image of two steady flickerless lights, respectively thrown on corresponding retinal areas, is obviously not equal to the sum of the two brightnesses. Its value is usually slightly above the arithmetical mean of the brightness of the uniocular components, provided that these do not differ too widely from one another. When the components are equally bright, the binocular increase has been variously estimated to be from one-tenth to one-thirtieth. It appears, however, that the increment rises with the degree of dark adaptation.

Fechner's Paradox.—When the uniocular images differ more widely in brightness, the binocular brightness becomes considerably less than the brighter of the uniocular components. This result is known as "Fechner's Paradox" (exp. 134). It reaches its maximum when the two brightnesses are in the ratio 1 : 25. When they are in the ratio 1 : 1·5, the binocular brightness is about equal to that of the brighter component. Even if unequal variations in the size of the pupils be eliminated, either by the use of small

artificial pupils or by paralysing the pupils by means of atropin, Fechner's paradox persists. It is absent when the darker of the two fields is presented before the brighter, and when the area of the former is made considerably smaller than that of the latter. No satisfactory explanation of Fechner's paradox has been yet advanced. Believing that the cortical paths of corresponding elements of the two retinæ are not identical, McDougall has suggested that the paradox may be due to the competition of the cerebro-retinal elements of each eye for the maximal total nervous energy which is, at the moment, available. Owing to such competition, the brightness contributed by the cerebro-retinal elements of each eye is less when the two eyes are stimulated simultaneously than when they are stimulated successively. Further, what each eye loses on this lower physiological level does not reappear in the higher psychological synthesis of the two images.

The Study of Orbital Movements.—The movements of the eyes have been studied by various methods, *e.g.* by observing the movements of a vessel of the conjunctiva, of a mark on the eyeball, or of after-images. They have also been studied by the cinematograph.

Listing's law states that the axis round which oblique movements of the eyes take place, is in the same plane as the axes round which simple vertical and horizontal movements take place (exp. 135). The law hence denies the occurrence of swivel (or wheel) rotation of the eyes around the optic axis; but it is found only to hold for parallel, or approximately parallel, positions of the visual axes. Under certain conditions, *e.g.* when the eyes converge and move obliquely, or when the head is inclined laterally, swivel rotation undoubtedly occurs.

Under ordinary circumstances, a very close association exists between binocular movement and accommodation, the lens becoming more convex with convergence, and less convex with divergence. But practice under certain con-

ditions (for example, the habitual wearing of prismatic glasses) can overcome this association and supplant it by one of different kind. Convergence and increased accommodation are also associated with contraction of the pupil.

BIBLIOGRAPHY.

W. Wundt, *Beiträge zur Theorie d. Sinneswahrnehmung*, Leipzig u. Heidelberg, 1862, 105; *Grundzüge d. physiol. Psychol.*, Leipzig, 1902, ii. 587. E. Hering, "Der Raumsinn u. d. Bewegungen d. Augen," in Hermann's *Handbuch d. Physiol.*, 1879, iii. 1te Theil, 343; *Beiträge zur Physiol.*, Leipzig, 1861–4, i.–v. H. L. F. von Helmholtz, *Handbuch d. physiol. Optik*, 2te Aufl., Hamburg u. Leipzig, 1896, 841. F. Hillebrand, "Das Verhältniss von Accomodation u. Konvergenz zur Tiefenlokalisation, *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1894, vii. 97. E. T. Dixon, "On the Relation of Accommodation and Convergence to our Sense of Depth," *Mind*, N.S., 1895, iv. 195. W. H. R. Rivers, "Vision" in Schäfer's *Text-Book of Physiology*, Edinburgh and London, 1900, ii. 1099, 1122. E. B. Titchener, *Experimental Psychology*, New York, 1901, ii. pts. 1, 2, chap. ix. F. B. Hofmann, "Die neueren Untersuchungen über d. Sehen d. Schielenden," in *Ergebnisse d. Physiol.*, 1902, 2te Abth. 801. J. W. Baird, "The Influence of Accommodation and Convergence upon the Perception of Depth," *Amer. Jour. of Psychol.*, 1903, xiv. 150. C. S. Sherrington, "On Binocular Flicker and the Correlation of Activity of 'Corresponding' Retinal Points," *Brit. Jour. of Psychol.*, 1904–5, i. 26. W. M'Dougall, "Note on the Principle underlying Fechner's 'Paradoxical Experiment,'" etc., *ibid.* 114. M. Straub, "Ueber monokulare körperliche Sehen," u.s.w., *Ztschr. f. Psychol. u. Physiol. d. Sinnesorgane*, 1904, xxxvi. 431. O. Zoth, "Augenbewegungen u. Gesichtswahrnehmungen," in Nagel's *Handbuch d. Physiol. d. Menschen*, Braunschweig, 1905, iii. 335.

CHAPTER XXI

ON BINAURAL EXPERIENCE

The Direction of Sounds.

Binaural Differences and the Perception of Sound.—The inequality in effect of a given sound upon the two ears plays an important part in determining our appreciation of its direction. It is a familiar experience that, when the source of a sound is placed asymmetrically with regard to the two ears, it can be localised with tolerable accuracy. With eyes closed and with head unmoved, we can correctly judge whether the source of the sound lies to our right or to the left, and, with less precision, whether it lies towards our front or back. When, on the other hand, the source of sound is placed symmetrically with regard to the two ears,—when, that is, the sound lies behind, above, or below the head, in the sagittal plane,[1]—our estimation of its direction is notoriously very erratic.

Tactual Differences.—The binaural differences, in virtue of which we are able to localise a given sound, have been referred by Wundt and others to the tactual sensations evoked by sound vibrations from the two auricles and tympanic membranes. But the evidence derived from introspection and from the study of subjects who are devoid of auricle and drum, lends little support to this view.

Labyrinthine Differences.—The suggestion has also been

[1] The sagittal plane is the plane of the sagittal suture of the skull, the median plane of the body.

put forward by Preyer that our powers of auditory localisation are connected with the peculiar orientation of the three pairs of semicircular canals in the three planes of space, the various canals being differently stimulated according to the direction of the sound. Münsterberg supposes that the effect of auditory stimulation of a given canal would be to cause the head reflexly to turn in the plane of that canal, and that the kinæsthetic sensations arising from such various head movements form the basis of our judgment of sound direction. But apart from other objections, it is inconceivable that sounds, coming from different directions, should differently stimulate the semicircular canals; for by the time they reach the inner ear, surely all vibrations of sound must have the same direction, however different their place of origin.

Temporal Differences.—A third possible cause of the unlike effects produced by a sound on the two ears lies in temporal differences of stimulation. It is obvious that a sound, the source of which is on one side of the head, must affect one ear before the other. But we have no evidence that such successiveness of excitation is essential for sound localisation. On the contrary, we are able uninterruptedly to localise continuous sounds. And if two forks of identical pitch be held to opposite ears and be continuously sounded, we hear a single sound localised either in the middle line or to one side of it, according as the two forks are sounding with equal or unequal intensity.

Phase Differences.—There are but three other conceivable ways in which a given source of sound may differently affect the two ears, namely, by virtue of differences in phase, in timbre, or in intensity. By differences in timbre we mean differences in the relative intensity of the overtones to one another and to the fundamental tone. By difference of phase we mean the effect due to the unequal distances of the two ears from the single source of sound, in consequence

of which the sound waves, falling at any moment on the two ears, are in unlike phase. We can experimentally show that changes in the phase relation of the sound stimuli reaching the two ears produce distinct changes in the apparent direction of the sound, whether the source of sound for each ear is the same or different (exps. 138, 139). Owing, however, to the easy conduction of sounds through the head from ear to ear (page 21), these changes of localisation, which at first sight appear to be directly due to dissimilarity of phase, may really be due to differences of intensity in the two ears; the differences of intensity arising from the interaction (by interference or summation) of the two series of waves of different phase.

According to Myers and Wilson, binaural phase differences owe their effect to the binaural intensity differences which they thus produce; hence it becomes unnecessary to adopt Lord Rayleigh's view that we are able to tell at which ear the phase of vibration is in advance, when we judge the direction of a laterally placed sound of low pitch. This view is inevitable, so long as we suppose that such a sound can only reach the more distant ear by the air. For it is a fact that the head is not large enough to throw an appreciable sound shadow when the sound is of low pitch and consequently of very great wave length. But the difficulty at once disappears, if we bear in mind how readily a sound is transmissible from ear to ear by bone conduction. Then it is easily demonstrable that the phase differences at the two ears produce differences of intensity.

Intensity Differences.—Indeed, there is ample evidence that binaural differences of intensity play the essential part in sound localisation. Other things being equal, the sound is localised on that side which receives the stronger stimulus (exps. 136, 137). The importance of binaural differences of intensity is well illustrated by the two following facts, chosen from many others.

In the first place, a tuning-fork placed anywhere on

the head is localised in that ear which receives the stronger stimulus.

Secondly, let an imaginary circle, a metre or more in diameter, be drawn horizontally round the head at the level of the ears, its centre lying midway between them; and let this circle be divided into quadrants, limited by the sagittal and the coronal planes.[1] Then it is found that a sound, placed at any point on the circumference of this circle (save exactly midway before or behind the head), is accurately judged by the subject to lie to his right or his left. But he is apt to confuse the anterior with the posterior quadrants of the same side. That is to say, he often wrongly supposes that a sound is as much in front of the transverse plane as it is really behind that plane (exp. 137). These confusions are just what one would expect on the basis of binaural differences of sound intensity.

Timbre Differences.—Inasmuch as the shadow effect of an obstacle increases with the shortness of the wave length of the sound, it follows that the sound shadow cast by the head must be different for the different overtones that are present in a given sound. That is to say, a laterally placed sound, reaching one side of the head, will be of different timbre from that reaching the other side through the air.

There is, however, another way in which the apparent timbre of a sound may alter with change in the position of the sound. We have evidence that the auricle itself has considerable influence in modifying the timbre (and intensity) of sounds, according to the direction in which they travel to the ear. The ticks of a watch, placed in front of the head, are of very different quality, compared with those of the same watch, placed behind the head. And when artificial auricles or flaps are attached to the ears, capable of being turned in any desired direction, various illusions of localisa-

[1] The coronal plane is a vertical plane between the two ears perpendicular to the sagittal plane.

tion can be produced, according as one or other ear is more favourably or unfavourably exposed to the partial tones of the sound. It has been urged by Mach that the auricles act as resonators, their effect depending on their position relatively to the direction of the impinging sound waves.

No attempt has yet been made to investigate the effects on our judgment of direction, experimentally produced by conducting to separate ears two tones of like pitch but of unlike timbre. Nevertheless the importance of the timbre is well shown in the extraordinary improvement effected by practice in localising sounds which are in the sagittal plane in front of, behind, above, or below the head. When sounds, thus placed, are consecutively given, their correct localisation must surely depend upon successive differences in their timbre.

If differences of timbre be so important, localisation should be possible when only one ear is stimulated. But owing to the ease with which sounds travel by bone conduction from one ear to the other, it is only possible to investigate the effects of uniaural stimulation in the case of individuals who are known to be absolutely deaf in one ear. In such subjects, localisation is extremely defective in regard to sounds which are placed on their deaf side. Yet here, again, considerable improvement occurs with practice.

Now these improvements of localisation that are produced by practice, alike in the binaural hearing of sounds in the middle line (page 286) and in the uniaural hearing of sounds situated on the deaf side, are far better marked for noises, and for sounds rich in overtones, than for pure tones. The tones of tuning-forks, for example, continue to be localised with great inaccuracy in such cases, even after considerable practice. Moreover, the subjects introspectively ascribe their improvement to their more delicate appreciation of differences of timbre of the sound according to the direction.

It may seem strange that even the most unmusical

should be so sensitive to differences in the timbre of sounds as to be able to localise them correctly. Yet this is hardly more surprising than the correspondingly universal ability to identify individuals by their voice.

Adaptation in Localisation.—Those who are partially deaf in one ear are able, nevertheless, to localise sounds with fairly normal accuracy. When the cause of such partial deafness is removable,—when, for example, it is due to the accumulation of wax,—the restoration of hearing is accompanied by a temporary erroneous localisation of sounds towards the recovered side.

When prismatic glasses or lenses are continuously worn, so that the visual field is shifted in one or other direction or is completely inverted, the old association between visual and auditory localisation at length breaks down, and sounds appear to come from the new visual direction, especially, of course, if their source be at the same time seen.

The Distance of Sounds.

Our estimation of the distance of sounds, although it is entirely independent of binaural hearing, may be considered here. It is based upon the intensity and the timbre of sounds, and upon previous experience.

The higher overtones relatively predominate in distant sounds, the lower in nearer sounds. Thus distant sounds appear sharper than nearer ones (page 31). By increasing the pressure within the middle ear, the free vibration of the ossicles, which subserve the transmission of lower tones, is impeded, while the higher tones can in large measure pass by direct bone conduction (page 20). This condition thus gives rise to the illusion that near voices are at a great distance from the ear.

In general, however, distance produces a greater effect on high than on low tones. The effect is also greater on noises than on tones and on consonants than on vowels. The

predominance of the lower overtones in near sounds, to which we have just alluded, may be due to the obliterating power possessed by low tones (exp. 26).

BIBLIOGRAPHY.

E. Mach, "Bemerkungen über d. Function d. Ohrmuschels," *Arch. f. Ohrenheilkunde*, 1875, ix. 72. Lord Rayleigh, "Our Perception of the Direction of a Source of Sound," abstracted in *Nature*, 1876, xiv. 32; *Philosoph. Mag.*, 1907 (6) xiii. 214; "Acoustical Observations," *ibid.*, 1877 (5) iii. 456. S. P. Thompson, "On Binaural Audition," *Philosoph. Mag.*, 1877 (5) iv. 274; *ibid.*, 1878 (6) vi. 383; *ibid.*, 1881 (5) xii. 351. C. Stumpf, *Tonpsychologie*, Leipzig, 1883, i. 208, 242, 395. W. Preyer, "Die Wahrnehmung d. Schallrichtung mittelst d. Bogengänge," *Arch. f. d. ges. Physiol.*, 1887, xl. 586. H. Münsterberg, "Der Raumsinn d. Ohres," *Beitr. zur experim. Psychol.*, 1889, ii. 182. M. Matsumoto, "Researches in Acoustic Space," *Studies from the Yale Psychol. Lab.*, 1897, v. 1. A. H. Pierce, *Studies in Auditory and Visual Space Perception*, New York, 1901. J. R. Angell and W. Fite, "The Monaural Localisation of Sound," *Psychol. Rev.*, 1901, viii. 225, 449. W. Wundt, *Grundzüge d. physiol. Psychol.* 5te Aufl., Leipzig, 1902, ii. 486. J. R. Angell, "A Preliminary Study of the Significance of Partial Tones in the Localisation of Sounds," *Psychol. Rev.*, 1903, x. 1. C. S. Myers and H. A. Wilson, "On the Perception of the Direction of Sound," *Proc. Roy. Soc.*, 1908, A, lxxx. 260; "The Influence of Binaural Phase Differences on the Localisation of Sounds," *Brit. Journ. of Psychol.*, 1908, ii. 363.

CHAPTER XXII

ON THE VISUAL PERCEPTION OF SIZE AND DIRECTION

THE visual perception of size depends on two principal factors,—the size of the retinal image and the distance at which the object is estimated to be.

Micropsia at the Fixation Point.—The size of the retinal image is considerably influenced by irradiation. Irradiation occurs in consequence of the diffusion of light on to neighbouring retinal areas. Such an overflow is, as we should expect, much more marked with a large than with a small pupil. Owing to irradiation, a white square on a black ground appears larger than an actually equal black square on a white ground. The apparent acuteness of the right angles within the annexed diagram (fig. 10) is due to the same cause.

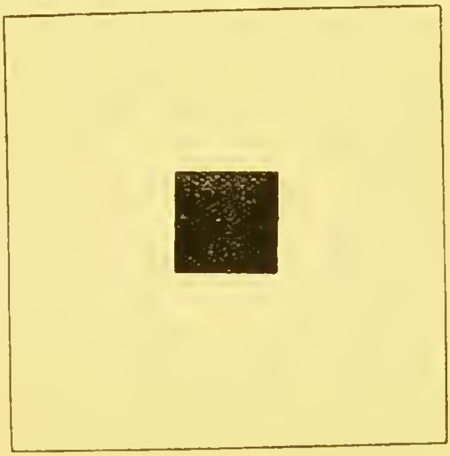

FIG. 10.

When the pupil is dilated under the influence of atropin, the size of letters printed in black type is considerably reduced. This form of micropsia under atropin is likewise due to irradiation. It has been called "micropsia at the fixation point."

The Dependence of Apparent Size on the Relation of an Object to the Fixation Point.—The apparent size of an object also depends on its position relatively to that of the fixation point. We have already seen reasons (page 277) for considering the fixation point as the central point or nucleus of our binocular field of vision, in terms of which all other, nearer or farther, objects in the field are interpreted.

In uniocular vision it is easy to convince oneself that objects which are nearer than the fixation point appear to be larger, and that those which are farther than the fixation point appear to be smaller, than they would appear when directly fixated. For if one eye be closed and the other be fixed on a near point, stationary objects beyond the fixation point, *e.g.* printed letters, will seem to grow smaller or larger, as the fixated point is moved nearer to or farther from the eye. These changes in size are frequently accompanied by inferred changes in position of the stationary objects. The latter may appear not only smaller but more distant, or not only larger but nearer than before. Further, the changes occur even when the moving point of fixation has only an imaginary existence.

Micropsia beyond the Fixation Point.—There is a micropsia, occurring under the influence of atropin, which cannot be attributed to irradiation. It has been called "micropsia beyond the fixation point." If one eye be closed and if the other atropinised eye make an effort of accommodation in regarding printed type, the print becomes markedly reduced in size. The micropsia also occurs when both eyes are used, provided that the ciliary muscle of each has been atropinised. It occurs, indeed, when each ciliary muscle is completely paralysed.

Many observers have attributed both forms of the micropsia produced by atropin—as well as the micropsia, which may occur late in life (in presbyopia)—to paresis or weakness of the ciliary muscle. In consequence of this paresis, it is supposed that a greater strain is thrown on the

muscle; that intenser kinæsthetic sensations arise during attempted accommodation; that the object is consequently assumed to be nearer than it really is, and therefore is judged smaller. We have pointed out, however, that one form of micropsia under atropin is due to irradiation (page 293). In the other form, which occurs even in complete paralysis of accommodation, it is difficult to understand how kinæsthetic sensations, whether of ciliary or of other origin, can play any part. Under these circumstances, we are compelled to adopt the view suggested by Rivers, that an intended but unaccomplished change of fixation point can produce the same effect upon the apparent size of an object as would occur if the volitional impulse had been able to achieve its results.

Fig. 11.

Influence of Estimated Distance on Size.—The influence of the estimated distance of an object on its apparent size is shown in the variable size of an after-image according to the distance of the fixation point at which it is projected (exp. 140). The apparent size of objects is similarly affected by a foggy or unusually clear atmosphere, or by suggestions of perspective in a drawing.

Micropsia in Retinitis.—The micropsia, often occurring in certain stages of retinitis, is doubtless to be ascribed to a separation of the retinal end organs by inflammatory exudation. The local signature of the retinal elements persists unaltered, and thus objects appear to be smaller than usual.

Comparison of Horizontal and Vertical Lines.—It is the opinion of many investigators, as we shall soon have occasion to observe, that either kinæsthetic sensations, due to orbital movements, or the impulses to such movements, form the basis of our visual estimation of height and breadth. Thus the tendency to overestimate the length of vertical lines relatively to horizontal lines (fig. 11) has been attributed to the greater effort involved in moving the eyes in a vertical than in a horizontal direction, and to the

more intense kinæsthetic experience thus involved (exp. 141).

In estimating long lines, eye movements are unavoidable, and here kinæsthesis may play some part in estimation. But in the estimation of shorter lines, eye movements are negligibly small. Besides, the overestimation of vertical lines occurs when they are presented for so short a time as to preclude the possibility of eye movement. We are thus forced to conclude either that kinæsthesis, however important for the development of spatial relations (page 279), is not essential for the occurrence of such illusions in adult life, or that the illusion is the result of other conditions, possibly of retinal origin.

Filled and Empty Space.—The empty space between two dots *a* and *e* (fig. 12) appears to the eye shorter than an equal distance, filled with dots. Those who regard kin-

FIG. 12.

æsthesis as all-important, urge that in the former case the eye is free to move from one extreme point to the other, while in the latter its movement is repeatedly arrested by the intervening dots.

Hering, however, offers an explanation of this illusion in purely retinal terms, based on the curvature of the retina. He reminds us that the distance between two points on a flat surface cannot correspond with the length of the arc of the curved retina which receives an image of that surface. Experience has taught us that the surface at which we are looking is flat, and we estimate the position of the points accordingly.

It is clear that, were no allowances made for the flatness of the surface *a c* (fig. 13), uniocular vision would locate the points *a*, *c*, *c*, at *a′*, *c′*, *c′*, respectively, and the flat surface would be seen as a curved one, *a′*, *b*, *c′*, *d*, *c′*, the curve corre-

sponding to the curvature of the retina, $\varepsilon\,\gamma\,\alpha$, and determined by the equality of the lines $a'\alpha$, $b\beta$, $c'\gamma$, $d\delta$, $e'\varepsilon$. But the known flatness of the surface causes the distance between any two points on it to be judged not on the basis of the curvature of the retina, but on the length of the chord drawn on the retina between them. Thus, our estimate of the unfilled distance between two points a, e (fig. 12), is dependent on the length of the retinal chord $\alpha\,\varepsilon$ (fig. 13), and our estimate of the broken distances $a\,b$, $b\,c$, $c\,d$, $d\,e$, is dependent on the lengths of the chords $\alpha\beta$, $\beta\gamma$, $\gamma\delta$, $\delta\varepsilon$. The sum of these four chords is obviously of greater length

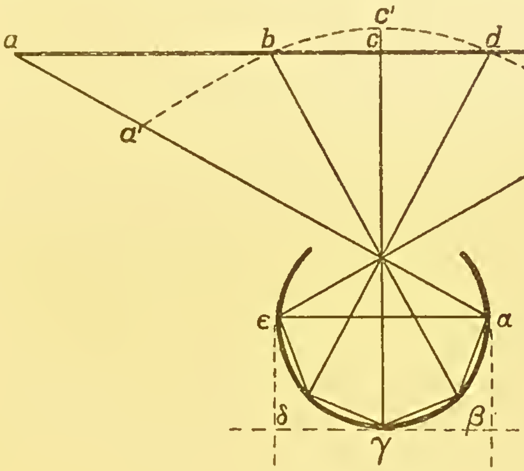

FIG. 13.

than the chord $\alpha\,\varepsilon$. Hence it comes about that an unfilled distance appears to be shorter than an equal but interrupted distance.

Estimation of Angles.—The eye tends to overestimate acute angles and to underestimate obtuse angles relatively to one another. As we shall see, this tendency has been introduced to explain most of the geometrical optical illusions. At Hering's hands it has received an explanation in purely retinal terms, dependent as before on the curvature of the retina. According to this explanation, the overestimation of acute angles only holds good for angles below

60°, above which underestimation occurs. This is in agreement with Brentano's statement that the tendency of the error is to overestimate small angles and underestimate large ones.

Wundt, on the other hand, attributes the error to the greater change of eye movement involved in traversing a small angle than in traversing a large one.

Contrast and Confluence.—The apparent length of a line or the apparent size or shape of a figure is influenced by the pressure and position of neighbouring lines or figures. The effect of the latter may be one of contrast or of confluence.

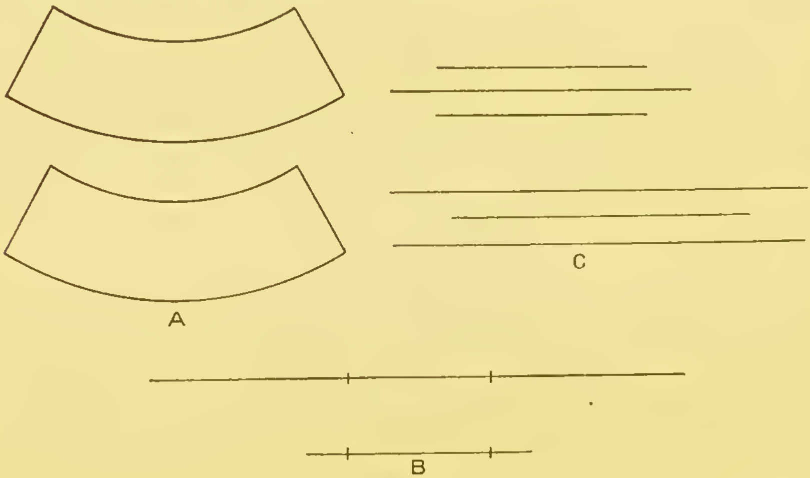

Fig. 14.

The diagrams A and B in figure 14 are examples of contrast. In A the figures are of precisely the same shape; but the upper side of the lower figure appears shorter than that of the upper, owing to its proximity to the longer side of the upper figure. Similarly the middle portions of the two lines in B, although actually equal, appear of unequal length, owing to the different influence of the terminal portions. Diagram C, on the other hand, is an instance of the opposite effect of confluence. The middle line appears longer, when bounded by longer, than when bounded by shorter lines. These and other geometrical illusions persist even when the

nature of the illusion has been pointed out. They cannot, therefore, be ascribed to errors of conscious inference, but are due to various factors, chief of which, perhaps, is our tendency, in judging the length of a part, to be inevitably influenced by the size of surrounding parts or of the entire figure.

Müller-Lyer's Figure.—The principle of confluence is

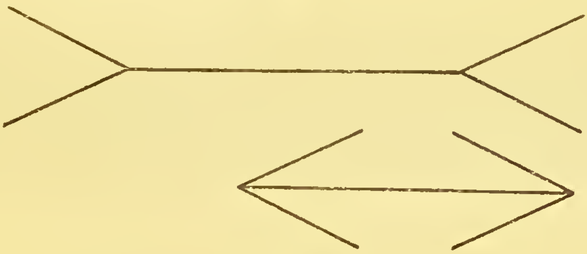

Fig. 15.

well seen in the Müller-Lyer illusion (fig. 15), where the upper of the two horizontal lines appears longer than the really equal lower line.

The illusion is more pronounced, the more prominent the end lines are made. It is weakened by relative strengthening of the horizontal line. If the end lines be lengthened, the illusion increases at first, but it diminishes (owing to the effect of contrast) when the relative length

Fig. 16.

of the end lines exceeds a certain limit. The illusion diminishes as the angles, which the end lines make with the horizontal, approach 90°.

It has been suggested that the Müller-Lyer illusion is due to errors in estimating large and small angles. But as the illusion persists in the right-angled form (fig. 16), this explanation falls to the ground.

The illusion was attributed by Einthoven to the diffu-

sion circles thrown upon the retina save at the central region of distinct vision. He supposed that the end lines would for this reason yield blurred dispersion images (fig. 17), and that we estimate the lengths of the horizontal lines by the position of the centres of the blurred images, which are nearer to one another in the one than in the other part

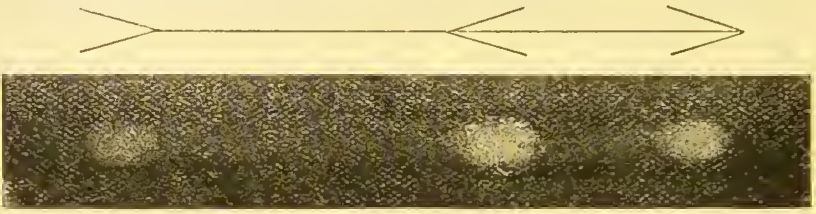

FIG. 17.

of the figure. The validity of this explanation is negatived by the fact that the illusion increases, the greater be the distance of the figure from the eyes, — that is, the more entirely the image of the figure fall within the region of distinct vision.

We do not, as Auerbach believed, necessarily take into

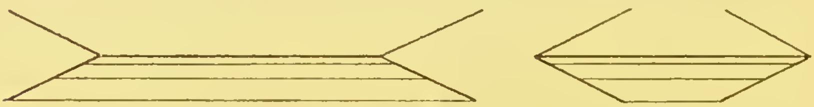

FIG. 18.

FIG. 19.

account the length of imaginary lines between the end pieces (fig. 18). For the illusion is still present in the form shown in figure 19.

There can be no doubt that the main cause of the illusion is due to the influence which is more or less unconsciously exercised on the subject by the different extents of the spaces partially bounded by the end lines. The

similar effects of eonfluenee in figure 14 *C* are referable to the same eause.

In eertain primitive peoples, the Müller-Lyer illusion is found to be less marked than among eivilised peoples; the former being able to take the end lines less into aceount and to attend more exelusively to the horizontal lines. For a like reason the illusion is mueh weakened, if the eolour of the end lines be different from that of the main lines.

Poggendorff's Figure.—The wrong estimation of angles has been applied to explain Poggendorff's illusion (fig. 20), where the line *c d* does not appear to be a prolongation of the line *a b*. It is supposed that the aeute angle at *b* is overestimated, giving the line *b a* an unduly horizontal slope. This, however, is a very ineomplete explanation of the illusion, as the following faets show.

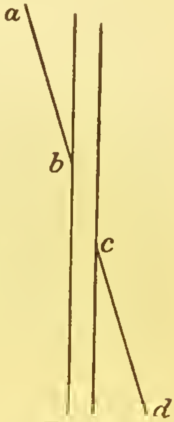

FIG. 20.

The illusion decreases with inereasing length of the interrupted line. It is much redueed when the figure is rotated so that this line beeomes vertieal or horizontal. Again, in the ordinary position of the diagram, the distance *b c* tends to be overestimated, while in the horizontal position of the interrupted line it is underestimated, as eompared with a line of the same length and direetion. We should expect in the absenee of other influenees that the unfilled space would always be underestimated. Its overestimation when the figure is upright is probably eonneeted with the overestimation of vertieal spaees.

Zöllner's Figure.—The wrong estimation of angles has been applied to explain Zöllner's figure (fig. 21). The illusion produeed by the eross lines is at its height when they form an angle of 30° with the two parallel lines, and is absent when the angle reaches 70°. It varies in degree aeeording to the distanee of the pattern from the eye, there being an optimal distance, beyond or nearer than whieh the

illusion decreases. The illusion also varies with the angle which the eyes preserve in regard to the pattern. It tends to disappear upon prolonged fixation, or when the eyes are moved in the direction of the parallel lines. It is much increased when the eyes are moved at right angles to them.

Influence of Suggested Activity.—Another explanation

Fig. 21.

which has been applied by Lipps to many of these geometric illusions, is that the patterns are regarded as having inherent force and so come to suggest certain mechanical activities, the radiating lines, for example, of Hering's figure (fig. 22), suggesting that the long parallel lines are pulled apart from one another at their centres. The illusion, however, may be explained by the overestimation of acute angles. It disappears on prolonged fixation.

Influence of Perspective.—These illusions have also been explained on the ground of the perspective which they

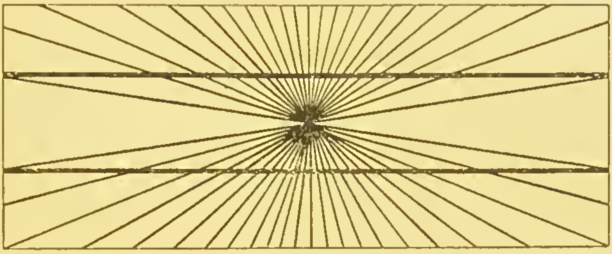

FIG. 22.

(consciously or unconsciously) suggest. The apparent perspective of simple figures, when regarded monocularly, is closely dependent on the point of fixation. Thus in the lines *a b*, *c d* (fig. 23 *A* and *B*), the point *c* tends to appear nearer than *d* when *c* is fixated, while if the eye wander to *d* the perspective is apt to change, *d* appearing nearer the observer than *c*.

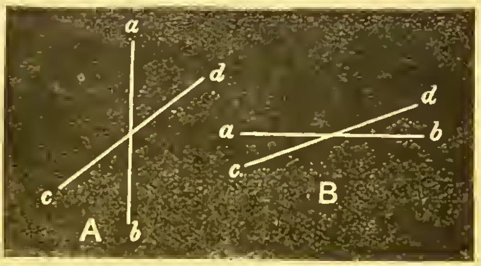

FIG. 23.

Similarly, the perspective of the well-known staircase figure (fig. 24) is apt to change according as the points *p* and *q* are fixated, in the former case appearing as a flight of steps, in the latter as an overhanging wall from which pieces have been cut out.

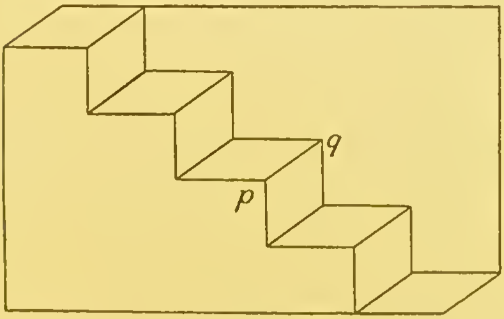

FIG. 24.

It is easy, however, to convince oneself that these eye movements often fail to reverse the perspective, and that

reversals may occur in spite of unchanged fixation. Movements of the figure in a horizontal or vertical plane have also been found to produce changes in the figure.

The General Conditions of the Geometric Illusions.—How far these factors of suggested activity and perspective play a part in the various illusions, is as yet undetermined. It is certain, however, that if they are effective at all, we are usually quite ignorant of their presence. In general, their action is an instance of what has been called "unconscious inference." We may hesitate, then, to term such factors psychological lest it be supposed that processes of reasoning are implied. If they influence our judgment at all, they may do so just as unconsciously as the simpler cerebro-retinal factors of contrast and confluence (page 298), or the still simpler retinal factors which Hering has advanced (page 296).

That eye movements play an important part in these illusions is gainsaid for various reasons. The illusions are not abolished, but, in many cases at least, are increased, when the figures are momentarily exhibited by instantaneous illumination and eye movements are thus prevented. Most of the illusions persist, perhaps reduced in degree, when the parts of the figures are combined stereoscopically. They are also present in the after-image. Moreover, recent photographic studies of the eye movements during the regard of such patterns show that the movements are too inconstant and variable to serve as a basis for the illusion. They show, too, that the range of movement is not greater in traversing one of the figures in the Müller-Lyer illusion than in traversing the other. It is only more hampered in the arrow-head figure. Yet in this figure the line is under-estimated; whereas the same hampering of eye movement is used to explain the overestimation of filled spaces (fig. 12).

Many, at least, of these illusions tend to disappear with continued practice, even though the subject remain ignorant throughout of the nature of the illusion. In the Müller-Lyer

illusion it has been shown that these effects of practice only occur when the exposure of the figure is prolonged. During momentary exposures the subject has no opportunity of learning to disregard the end lines and to limit his attention to the horizontal line the length of which is being estimated.

The Apparent Size of the Sun and Moon.—The causes of the apparent increase in size of the sun and moon at the horizon have been the subject of much controversy. The illusion varies widely in different individuals, and from time to time in the same individual. The enlargement suddenly becomes much greater in the immediate vicinity of the horizon.

The usually given explanation is that we judge the sun and moon to be more distant at the horizon than at the zenith, and that therefore we infer that they are larger at the horizon. It is supposed that one reason for the apparently greater distance of the sun and moon at the horizon lies in the atmospheric haze near the earth's surface, which especially affects the distinctness and colour of the sun and moon in that position; and that another reason lies in the number of terrestrial objects intervening between the observer and the sun or moon at the horizon, thus providing a filled distance which seems longer than the equal unfilled distance between the observer and the sun or moon when it is at the zenith (page 296). It has also been thought that the absence of other objects at the zenith, with which the heavenly objects can be compared, accounts for the apparent difference in their size; whereas at the horizon the sun or moon come to be regarded as one of the terrestrial objects. Other causes, *e.g.* the size of the pupil and movements of the lens, have been also suggested. The first mentioned of these factors is probably the most important, and some of the others may undoubtedly play a subsidiary part. It is wrong, however, to say that they result in a judgment that the sun or moon is more distant at the horizon than at the zenith.

As a matter of fact, the heavenly bodies at the horizon appear to be not farther but nearer than at the zenith.

The illusion has been experimentally studied by using a mirror so as to reflect the sun or moon at the horizon to the zenith, or *vice versâ*; and by regarding the moon at the zenith in a supine position and the moon at the horizon with the head inverted between the legs. The results, however, are so contradictory that they only show the need for further study of the many factors which enter into the illusion.

The greater muscular strain involved in looking upwards has also been advanced as an explanation. When the plane of regard is raised, the two eyes converge more and more, and this is supposed to give the effect of increased nearness or diminished size.

The form of the sky is unquestionably an important factor in the illusion. It usually appears to be not hemispherical, but flattened at the horizon. Now objects, shining through the vault of heaven, are regarded as if they were set in this flattened surface, and the apparently greater distance of the sky at the horizon leads to an apparent enlargement of the heavenly objects where they rise or set.

The cause of this flattening of the sky at the horizon has been much debated. It has been referred to the presence of intervening objects on the earth's surface, to the results of changing the direction of gaze, and to the difference in coloration of the sky at the zenith and at the horizon, which is due to differences in transparency, density, and brightness of the state of air. Probably each of these is a determining factor.

BIBLIOGRAPHY.

E. Hering, *Beiträge zur Physiologie*, Leipzig, 1861, Heft i. G. Heymans, "Quantitative Untersuch. ü. d. 'optische Paradoxon,'" *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1895, ix. 236. V. Henri, "Illusions et Hallucinations," *L'Année psychol.*, 1896, iii. 495; *ibid.*, 1897, iv. 538.

W. H. R. Rivers, "On the Apparent Size of Objects," *Mind*, 1896 (N.S.), v. 71; *Reports of the Cambridge Anthropological Expedition to the Torres Straits*, 1901, ii. 97; "Observations on the Senses of the Todas," *Brit. Journ. of Psychol.*, 1904–5, i. 339. T. Lipps, *Raumästhetik u. geometrisch-optische Täuschungen*, Leipzig, 1897; "Zur Verständigung über d. geometrisch-optischen Täuschungen," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1905, xxxviii. 241. W. Wundt, *Die geometrisch-optischen Täuschungen*, Leipzig, 1898. E. B. Titchener, *Experimental Psychology*, New York, 1901, i. expt. xxix. A. H. Pierce, *Studies in Auditory and Visual Space Perception*, New York, 1901. E. Reimann, "Die scheinbare Vergrösserung d. Sonne u. d. Mondes am Horizont," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1902, xxx. 1, 161; *ibid.*, 1905, xxxvii. 250. E. Claparède, "L'Agrandissement et la Proximité apparents de la Lune à l'Horizon," *Journ. de Psychol.*, 1905, v. 121. C. H. Judd, "The Müller-Lyer Illusion," *Psychol. Rev.*, Monograph Suppl., 1905, vii. No. 1, 55; "Practice without Knowledge of Results," *ibid.*, 185. C. H. Judd, C. N. M'Allister, and W. M. Steele, "Introduction to a Series of Studies of Eye Movements by Means of Kinetoscopic Photographs," *ibid.*, 1. E. O. Lewis, "The Effect of Practice on the Perception of the Müller-Lyer Illusion," *Brit. Journ. of Psychol.*, 1908, ii. 294. G. Dawes Hicks and W. H. R. Rivers, "The Illusion of Compared Horizontal and Vertical Lines," *ibid.*, 243.

CHAPTER XXIII

ON TIME AND RHYTHM

Time.

Temporal Fusion.—We have seen that, during and after its application, a stimulus evokes a whole series of changes in consciousness. We have, for example, the developing, the full and the fading sensation, the after-sensation, and the primary memory image. We recognise that these stages vary according to the kind of sensation, and that a different length of time is needful for the undisturbed course of different sensations in consciousness.

When we are attending to such a series of changes evoked by a momentary stimulus,—when, so to speak, we are living out an impression,—our experience of time is reduced to its simplest objective conditions. We see that the apparent length of the time depends upon the number of changes in the state of consciousness, and upon the movements of attention, which are produced by, or of themselves produce, those changes.

When two momentary sounds are separated by a brief interval, of about 550^{σ}, the various changes in consciousness, to which we have just referred, can be comprehended without difficulty as a single whole; they are subsumed into a unitary state of consciousness. The interval between the two sounds appears to have the specific character of "moderate" or "adequate" length; and the entire series of events—sound, interval and sound—lies within what has been called

the "specious" or "sensory" present. This is so, because a sound needs about 550$^{\sigma}$ for the development of its complete effect on consciousness. When a second sound follows after the lapse of this interval, the whole series of events is combined and apprehended as a present whole with a maximal degree of ease and agreeableness. If, on the other hand, the second sound occur somewhat sooner, the complete development of the effect of the first sound is interrupted, and the interval, instead of appearing "moderate" or "adequate," is now adjudged absolutely "short." Correspondingly, intervals which are longer than the "adequate" interval are termed absolutely "long."

The interval between two such sounds can be increased up to about 4000$^{\sigma}$, without the loss of the power of combining the successive changes in consciousness into a unity. But the combination, instead of taking place passively, demands an increasing effort on the part of active attention as the interval is lengthened. So long as the interval does not exceed about 4000$^{\sigma}$, it is possible, by means of strained attention, to experience the interval immediately as a single percept. Beyond this limit, the interval is immediately experienced as a number of component parts; only by representation or conception can it be regarded as a single whole. These limits, however, vary with different individuals, and according to the nature and intensity of the limiting stimuli. They are materially modified by certain drugs, *e.g.* alcohol, opium, and Indian hemp.

The Effect of Varying the Stimulus.—When a still shorter time interval, less than 400$^{\sigma}$, is allowed to elapse between two like stimuli, its apparent length depends upon the nature of those stimuli.

An interval occurring between two sparks which are heard seems shorter than the same interval between two sparks which are seen. So, too, an interval limited by noises appears longer than an equal interval limited by electrical stimuli. Again, if three stimuli be consecutively

presented, the first two being light stimuli, the third being an auditory or a tactile stimulus, the interval between the second and third appears to be longer than the really equal interval between the first and second stimuli. Such variations in the apparent length of a short time interval, according to the nature of the limiting stimuli, are doubtless dependent upon the different course which, as we have already indicated, different sensations pursue. Some quickly come and go, others occupy the attention for a longer period. Doubtless the extent to which the fading memory image of the first stimulus is overlapped by the arrival of the second presentation constitutes an important factor in the estimation of short intervals.

Filled and Empty Intervals.—The apparent length of the interval elapsing between two stimuli is influenced by the number and the nature of experiences occurring during that interval. When two equal intervals are compared by a subject, who is idle during the first but occupied in reading aloud during the second interval, the latter almost invariably appears to be shorter than the former, whatever be the order in which the two intervals are given. So, when two sound stimuli limit a given interval, and when this interval is compared with an equal interval which, instead of being merely limited by, is also occupied by sounds, the "filled" interval appears longer than the "empty" interval, the error of estimation increasing up to a certain point with the number of sounds filling the interval (exp. 143). The same holds for visual, and still more markedly for tactile stimuli.

The error is said to diminish as the length of the interval increases, and even to be reversed when the times are sufficiently long. There are other complicating conditions which alter the illusion, but in the simplest form of the experiment the error we have described is that which is commonly met with. The impressions, occupying a filled interval, interfere with one another's free development, and

the attention, instead of being passively occupied with an unimpeded experience, is directed successively to numerous discrete presentations; whereas in the case of the empty interval, the impressions which begin and end it are at liberty to develop without interruption.

The Filling of Empty Intervals.—But, strictly speaking, an interval is never "empty"; an unfilled interval is impossible. Even when our surroundings are absolutely quiet, respiratory and cardiac movements are still occurring, and the muscles of the sense organs or other parts are always undergoing contraction. It has been supposed that our ability to estimate a fairly long "empty" interval depends on the kinæsthetic and organic sensations which arise from these various sources and occupy the interval. It is true that, when subjects are allowed to use whatever aids they like in order to remember the length of an interval, they at first have recourse to voluntary movements of the head or extremities, or to voluntary regulation of respiration. They endeavour to reproduce during the second interval the exact sensations with which they have filled the first interval, and they estimate the relative length of the second interval by the success with which it can be thus filled. With increasing practice, however, subjects gradually discard all such sensory units. They come to deem them disturbing rather than helpful, and finally they no longer make conscious use of them in the reproduction of intervals; just as occurs, indeed, when we wake each morning after a constant interval of sleep; or when through post-hypnotic suggestion we perform a dictated act after a dictated interval.

Experimental Methods.—There are two principal methods employed in experiments on time estimation. The first is a method of reproduction. A time interval is presented by the experimenter; the subject has to repeat this interval as correctly as possible (exp. 142). The second is a method of comparison. Two intervals are presented to the subject,

who is asked to determine whether one is longer or shorter than or equal to the other. These methods have been employed with or without the occurrence of a pause between the two intervals. When no pause is given, the stimulus terminating the first interval also serves to start the second. Sufficient has already been said, in the discussion of the psycho-physical methods, for us to realise that important differences must arise, according as the method of reproduction or comparison is used, and according as no pause, a shorter or a longer pause, is inserted by the subject or by the experimenter between the two intervals. The nature of some of these differences will be apparent presently.

The Indifference Interval. — By whatever method we proceed, one result of experiment on time estimation seems to stand out very clearly. Short intervals tend to be overestimated, and long intervals to be underestimated. There is hence an indifference interval, marking a transition from the one direction of error to the other, which is on the average correctly estimated (exp. 142). The earliest observers found that the value of the indifference point ranged between 1500^{σ} and 3500^{σ}, according to the conditions of experiment, but their results were for three special reasons unreliable. The apparatus used was not delicate enough to secure accurate presentation and measurement of the intervals, or to maintain a uniform intensity of the sounds limiting them. In the second place, the psycho-physical method chosen was not employed with sufficient care. Thirdly, the volitional movements made by the subject in reproducing a given interval introduced disturbing features which later observers obviated by using the method of comparison. Under subsequently improved conditions of experiment the indifference interval has been shown to lie between 700^{σ} and 800^{σ}. Intervals shorter than this are overestimated, those longer are underestimated.

Certain observers claim that several other indifference intervals occur, at points which are approximately odd

multiples of the interval 710^σ, namely, at 2·15, 3·55, and 5 seconds. It has also been said that higher multiples, namely, 6·4, 7·8, 9·3, and 10·65 seconds, are intervals at which the error of estimation is relatively at a minimum.

Münsterberg, who believed that respiratory movements are the basis of our estimation of long intervals of time, attributes these multiples of the shortest indifference interval to multiples of the respiratory rhythm. Other organic and more obscure rhythms have been also invoked. The entire subject, however, needs re-investigation.

The Effect of the Pause.—The comparison of two intervals of time affects and is affected by the length of pause which intervenes between them. It has been found that, when the subject is allowed to make what pause he likes before he reproduces a given interval, the pause is relatively longest when the given interval is shortest, and that, as the interval which he has to reproduce is increased, the pause absolutely increases up to a certain length of interval, after which it again declines. Attention has also been called to the fact that, when the experimenter presents a pause which is equal to the first interval, it appears to the subject longer than the first interval. This may affect his judgment when the second interval is presented to him.

The Effects of Expectation and Surprise.—A further effect of an unusually long or short pause is caused by the feelings of expectation or surprise. When a pause of unusual length or shortness occurs, the feelings of expectation or of surprise undoubtedly determine our attitude to the second interval, and so affect our estimation. The feeling, for example, which would be occasioned after an unduly long pause by the start of a second interval, is said to lead to underestimation of the latter.

These feelings also play a more direct part in the estimation of intervals. When pairs of intervals are presented, the one a constant, the other a variable interval, and the subject has to judge between their length, he becomes

attuned to the constant interval, and to expect a given length of interval in the variable. According as the latter ends sooner or later than he had been led to expect, the judgment "shorter" or "longer" is recorded of the variable. Contrast, arising from side comparisons (pages 213, 272), exercises a similar effect.

The Absolute Impression.—So far we have presupposed that time intervals are "compared," and we have left out of account the possible play of the absolute impression, which dispenses with true comparison. The absolute judgment induces us to disregard the first of the two presentations and to attend solely to the second; we are ready to estimate the second, even though we have lost all recollection of the first (page 267). The first presentation is only important in so far as it modifies the attunement of our judgment.

In favour of the existence of the absolute impression in the sphere of interval comparisons, we have the following experimental evidence. Let us suppose that the standard interval measures 600^σ, and that it is followed, after a varying pause of 1·8, 14·4, 54 or 108 seconds, by one of a series of variable intervals ranging between 540^σ and 660^σ. Now the shortest of these variable intervals, when judged by the subjects on the ground of its specific character (page 308), is termed absolutely "short." The play of the absolute impression, when pairs of standard and variable intervals are exhibited to the subjects, is indicated by the fact that the number of judgments "second interval shorter" is found to be practically uniform in spite of the above variations in the length of the pause. If the two intervals, the standard and the variable, be really compared, we should expect the length of the pause between them to have a distinct effect on the frequency of any particular judgment. Moreover, the judgments "second interval *distinctly* shorter" are found to increase in frequency with the length of the pause. This, again, we should not expect if a true process of comparison takes place; it points rather to reliance on the absolute

judgment, which becomes all the more striking in effect, the longer the pause before the occurrence of the time interval to which it refers.

RHYTHM.

Subjective Accentuation of Rhythm.—The appreciation of regular intervals between presentations or between recurring groups of presentations, is the basis of rhythm. The presentations may be tactual, auditory, or kinæsthetic; they may be similar or dissimilar.

The simplest material for rhythm consists of a series of identical, regularly repeated, and equally accented stimuli. When the members of such a series are passively attended to, they tend to separate into groups. If, for example, a metronome is rapidly beating with regularity and uniformity, the listener who preserves a passive attitude will observe that the sounds arrange themselves in groups, usually of two or four sounds, the first member of each of which becomes strongly accented. The effect of this subjective accentuation is that the intervals between successive groups appear longer than those between the members of such groups (exp. 144).

Subjective accentuation of a simple rhythm may be changed at will; subjectively accentuated groups of three and of six may be realised. Groups of five are only with difficulty obtainable, and cannot easily be maintained.

When the members within each successive group of auditory stimuli are of like loudness, but of unlike duration, the longest lasting member of each group appears to be the loudest; it receives the accent, and is apprehended as the first of each group.

Objective Accentuation.—The simplest and most easily maintainable rhythm, obtained by objective accentuation of an otherwise uniform series of sounds or movements, is the troche – ◡. The iambic ◡ – is more difficult to maintain, owing to its tendency to pass over into the trochaic measure. Similarly the anapæst ◡ ◡ – passes over to the dactyl – ◡ ◡.

That is to say, there is a general tendency for the series to be grouped so that the accent is received by the first member of every group.

It will be noticed that the objectively accented member appears not only to be louder, but to last longer and to be followed by a longer interval of time than the other members (exp. 145). Thus the effect of accentuation, whether subjective or objective, is always to divide a series of auditory stimuli into feet or bars.

Maintenance and Reproduction of Rhythm.—The accuracy with which a prescribed rhythm can be maintained also varies with the individual and with the rate at which the presentations succeed one another. There are individual differences in the rate which is most correctly reproduced, and these have been attributed, on inadequate evidence, to individual differences in the rate of walking. Reproduction is stated to be most accurate in the case of impressions separated by an interval of about 700^{σ}. When quicker rates than this are given, they are reproduced more quickly; when slower rates are given, they are reproduced more slowly (exp. 146).

BIBLIOGRAPHY.

L. T. Stevens, "On the Time-Sense," *Mind*, 1886 (O.S.), xi. 393. H. Münsterberg, *Beiträge zur experimentellen Psychol.*, Freiburg, Hefte ii., iv., 1889, 1892. F. Schumann, "Ueber d. Gedächtniss f. komplexe gleiche Schalleindrücke," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1890, i. 75; "Unterschiedsempfindlichkeit f. kleine Zeitgrössen," *ibid.*, 1891, ii. 294; "Ueber d. Schätzung kleiner Zeitgrössen," *ibid.*, 1893, iv. 1; "Zur Psychol. d. Zeitanschauung," *ibid.*, 1898, xvii. 106; "Zur Schätzung leerer von einfachen Schalleindrücken begrenzter Zeiten," *ibid.*, 1898, xviii. E. Meumann, "Beiträge zur Psychol. d. Zeitsinns," *Philosoph. Stud.*, 1892, viii. 431; *ibid.*, 1893, ix. 264; "Untersuchungen zur Psychol. u. Ästhetik. d. Rhythmus," *ibid.*, 1894, x. 249; "Zur Psychol. d. Zeitbewusstseins," *ibid.*, 1896, xii. 127. T. L. Bolton, "Rhythm," *Amer. Journ. of Psychol.*, 1893, vi. 145, 310. B. Edgell, "On Time Judgments," *ibid.*, 1903, xiv. 418. J. Quandt, "Das Problem d. Zeitbewusstseins," *Arch. f. d. ges. Psychol.*, 1906, viii. (Literaturbericht), 143. D. Katz, "Experimentelle Beiträge zur Psychol. d. Vergleichs im Gebiete d. Zeitsinns," *Ztsch. f. Psychol.*, 1906, xlii. 302, 414.

CHAPTER XXIV

ON ATTENTION

Its Effects on the Apparent Order of Presentations.—When two stimuli are simultaneously applied to two different sense organs, they are, as a rule, not perceived simultaneously. If, for example, an auditory stimulus be applied at the same moment as a visual stimulus, the subject experiences it sooner than the latter. For a flash of light to be perceived earlier than a momentary sound, the light must precede the sound by from 60^{σ} to 100^{σ}; when this interval falls to about a quarter of this value, the sound is experienced before the light.

These conditions are primarily due to the longer latency of visual as compared with auditory excitation. They are, however, also affected by the chance direction of the subject's attention. That impression which he happens at the moment to be expecting tends to make its appearance earlier in consciousness. Perhaps the attention of some subjects inclines of its own accord towards one rather than towards the other of two different simultaneous stimuli which are expected. This is a possible explanation of the fact that the time intervals just mentioned vary considerably in different individuals.

The time intervals are materially affected by volitional changes of attention. In one investigation, for example, it was found that, when attention was volitionally directed to the expected light stimulus, the latter had to precede the sound stimulus by 95^{σ} in order that it might be appre-

hended first, and that, when this interval was reduced below 28$^\sigma$, the sound was experienced before the light. If, on the other hand, the same subject directed his attention to the expected sound, the latter apparently preceded the light stimulus, when, actually, it followed it by an interval of about 50$^\sigma$.

Similar results have been given by an instrument known as the "complication clock." This essentially consists of an index hand, which is watched by the subject as it repeatedly revolves with uniform speed before a white clock face. At any point in the course of the index, determined by the experimenter, the subject receives some other impression, *e.g.* the strike of a bell, a noise, an electric shock, or a combination of these. After several observations, the subject has to decide the exact position on the dial of the revolving index at the moment when he heard the bell or the noise, or felt the electric shock.

The time displacements, as they have been called, which occur with this apparatus, resemble those that we have already described. When the subject's attention is especially directed to the index, the bell is heard too late, *i.e.* there is a positive time displacement. When he pays greater attention to the bell, it is heard too soon, *i.e.* there is a negative time displacement.

As might be expected, the position ascribed by the subject to the index is found to depend on the graduation of the clock face. He tends to place the index exactly at a mark rather than between two marks, and to place it at the most familiar positions (*e.g.* corresponding to the number 12, 6, 3, or 9 on the ordinary clock face) rather than at an intermediate position.

The error of displacement is dependent on the practice which the subject is allowed and on the speed and direction of rotation of the index. According as the hand is slowly or rapidly moving, there is within certain limits a greater tendency to negative or to positive time displacement

Between lies an indifference point, *i.e.* a speed of rotation at which there is no displacement. With an index length of 25 cm. this indifference point occurs at a speed of revolution varying between 2 and 5 secs. according to the individual. The error varies according to the number of impressions which are simultaneously introduced, and according as these impressions involve the same or different sense organs. Unfortunately, a psychological interpretation of these and other results, obtained by the complication pendulum, is too difficult and controversial to be undertaken here.

The General Effects of Attention on Presentations.—The direction of attention influences not merely the order of appearance of two nearly or absolutely simultaneous different stimuli, but, as we have seen, it likewise affects the relative distinctness and duration of the stimuli and the absolute and differential thresholds of sensation. Whether the intensity of sensation in general is increased by attention and reduced by distraction is a matter of controversy, which has not yet been finally settled by experiment.

These general effects of attention on the experience of a presentation are most readily explicable in terms of facilitation. When our attention takes a certain direction, a condition is set up in which conscious and unconscious states tend to be augmented or inhibited, according as they are favourable or unfavourable to the continuance of the theme of attention. When we attend expectantly to a coming stimulus, everything is favourable for its reception. If the stimulus be of a visual kind, the eyes are already fixated and accommodated, the whole muscular and nervous system is in readiness to receive the stimulus. It is correspondingly unprepared to receive any other stimulus, and it resists the development of any other presentation. Not only are the appropriate muscles of the sense organs held in preparation, but the sensory cortical centres are attuned, if not excited, by reason of the image of the coming stimulus

being held in consciousness. The preparedness of these centres is possibly further increased by a drainage into them of nervous energy from the afferent impulses which result from the above-mentioned muscular contractions; but at present this hypothesis of drainage is not supported by sufficient physiological evidence.

Fluctuations of Attention.—When attention is directed to continuous stimuli of feeble intensity, the sensations to which they give rise are liable to fluctuation (exps. 147, 148). If, for example, a faint grey band on a white or black background be fixated, it comes and goes; we are not continually conscious of its presence. These fluctuations have sometimes been ascribed to the influence of cardiac or respiratory movements, but their frequency seems to be independent alike of that of pulse and of breathing. The fluctuations usually recur every three or four seconds; but their periodicity may vary from a few seconds even, it is said, to more than a minute. These variations depend on the absolute strength and extent of the stimulus, on its strength relative to that of the surrounding background, and on other factors of which at present we know little.

Similar fluctuations have also been observed in the case of intermittent auditory stimuli, *e.g.* the faintly heard ticks of a watch. They have also been described in the case of weak or waning continuous sounds, but observers are not in agreement on this point.

These fluctuations are commonly termed "fluctuations of attention"; but this begs the question of their origin. From time to time attempts have been made to explain these fluctuations in terms of muscular changes, or of changes in the condition of adaptation, within the sensory apparatus. It has been proved that the ciliary muscle of the eye contracts unsteadily, and observations have been published which go to show that, as a rule, these muscular oscillations are synchronous with the "fluctuations of attention." If this be so, we may suppose that, as the lens periodically

relaxes, the retinal image is momentarily thrown out of focus, its clearly defined margins giving place to blurred diffusion circles, which are of too weak intensity to be seen. Another explanation is that, owing to the well-known unsteadiness of orbital fixation, the eyes unwittingly shift, whereupon an image of the grey band is cast on a new retinal area, fresher and more sensitive than the previous area, which, owing to adaptation, no longer responds to the grey stimulus.

But this unsteadiness of the muscles belonging to the sense organs is not a complete explanation of the fluctuations which we are considering. Visual sensations continue to fluctuate after the muscles of the lens and pupil have been paralysed by atropin, or after the lens has been removed by operation. The fluctuations recur so regularly that it is unlikely that they are due to involuntary eye movements, and they persist during voluntary movement of the eyes. Auditory sensations fluctuate in persons who, owing to disease, have no tympanic membrane upon which a periodically contracting tensor tympani muscle might exercise its effects. Moreover, these fluctuations are not confined to the eye and ear; they are present (although observers are not in agreement here) in the case of sense organs which are unprovided with adaptative muscular apparatus.

When we call to mind that similar fluctuations occur in visual after-images (page 80), in memory images (page 148), in retinal rivalry (page 280), and in volitional tension (page 194), we may feel disposed to believe that they are each the expression of the oscillatory character of psychophysical processes in general. The physiological basis of such oscillations is at present uncertain, but some experimental evidence is claimed in favour of referring it to those rhythmic changes in blood pressure which are seen in Traube-Hering waves, and are due to the rhythmic activity of the vaso-motor centre in the bulb.

There can be no doubt that volitional attention has

some influence on the frequency of these fluctuations of attention. Its influence is similarly evident in the case of two different rival colour sensations, each derived from a different eye; that sensation, to which attention is directed, being retained longest and being made to predominate, to the more or less complete exclusion of the other. It has been suggested that this control by the attention is in part due to the muscular accommodation which attention brings with it, and to the increased sensory experience arising therefrom. But this, even if it be a partial, is not the whole explanation of the effect, for the phenomenon does not disappear after atropin has been applied to one or both eyes.

Involuntary changes of fixation do not afford a complete explanation of the alterations undergone in such geometrical designs as figure 24 (page 303). It is true that when the eyes are fixated on the point *p*, the design tends to take the form of a staircase, and that when the eyes are fixated on the point *q*, it tends to change to an overhanging piece of wall. Frequently, however, either form of the figure may appear, whichever of the two points be fixated, and the figure may alternate between one form and another in the absence of any demonstrable eye movement. So also in the case of the familiar puzzle pictures, where a man's head, for example, has to be found amid a forest of trees, there is the same obscure and involuntary oscillation between the two different possible interpretations of the same drawing.

Distraction.—The effects of distraction of the attention have been submitted to experimental investigation. It is found that if a disturbance is either continuous or regularly intermittent, the subject soon adapts himself to it. When disturbance recurs with irregular interruptions, its effects are generally unfavourable. Experiment has shown that, while an individual is maintaining a slow rate of simple rhythmical tapping, he is capable of performing easy arithmetical calculations, or of repeating sentences as efficiently as

when he is not tapping. Disturbances enter only when the rate of tapping is very rapid, or when he is desired to maintain a complicated rhythm. For a short time, however, a paradoxical result may be sometimes obtained, the subject being more attentive, and executing a prescribed task more rapidly in the presence of, than in the absence of, such a distracting presentation. That is to say, the strain necessary to avoid disturbance directly leads to increase in the degree of attention given to the task prescribed.

The most marked effects of distraction occur when the disturbing and the disturbed processes are of closely similar nature, as in writing one poem while reciting another.

It is obvious that the carrying out of rhythmical taps involves but dimly conscious processes, which may be relegated to the very margin of the field of attention. When, however, the disturbing process is so important that it must needs occupy the focus of attention, only two alternatives are possible. Either the series of disturbing and disturbed processes must become united by psychical fusion into a succession of *single* states of consciousness,—and this is rarely possible,—or the focus of attention must oscillate between the two tasks while each is being carried on. The latter is doubtless what must occur in the example just quoted, wherein the subject attempts to write one poem while reciting another.

Span of Apprehension.—The fact that a group of presentations can be apprehended in a very brief and single act of attention, and subsequently analysed, is illustrated in experiments on the so-called "span of apprehension" (exps. 149, 150).

If a varying number of points, lines, numbers or letters be momentarily exhibited before the eye, it is found that only a limited number can be "apprehended" in a single exposure. In such experiments care must be taken that the exposure is so short—less than one quarter of a second—that the possibility of eye movements is excluded. The

eyes should be accurately fixated on the empty area at a given signal before the dots or lines or other objects are exposed on it. The various objects should be silently exhibited and withdrawn, all at the same time, and shown for a known and accurately variable period. Care should be taken that the illumination of the objects does not appreciably disturb the state of retinal adaptation of the subject.

With these precautions it is found that only about five separate impressions (points, lines, numbers or letters) can be counted after they have been momentarily seen. When short words, of three or four letters, are substituted, again only about five words can be apprehended. That is to say, only five separate units can be analysed from the experience resulting from a very brief act of attention. Experiments have shown that the number of units which can be analysed by different subjects is related to individual differences in the duration and vividness of the memory after-image.

Each of these units may, as is clearly the case with short words, be composed of smaller units, which are psychically apprehended as a larger unit, just as the larger units themselves are, within the limits of the "span of apprehension," apprehended as a unitary state of consciousness. It is obvious that increasing practice may permit of the formation of still more complex units.

Investigations have been likewise made with regard to groups of successive instead of simultaneous stimuli. Inquiries have been directed to the number of metronome taps which a subject, without counting, can recognise as a whole. It is found that when the taps succeed one another every quarter of a second, the subject can just apprehend groups of eight. If one group (the first member of which is accented by a bell) consists of eight taps, while another group (similarly accented) consists of seven taps, the subject can, without counting, distinguish the one group from the other; but beyond groups of eight taps, his judgments are unreliable.

The Measurement of Attention.—Four principal methods have been applied or suggested to this end. In the first the rate of fluctuations of minimal stimuli (page 320) is observed under different conditions of attention. The second method consists in measuring the organic concomitants of attention (page 333). In the third method the efficiency with which a certain test is performed is taken as a measure of the attention. Among the tests which different observers have chosen for this purpose, are the spatial and differential thresholds, reaction times, the counting or marking of dots during short exposures, learning, and the letter-erasing test.

In all three methods, what is measured is not the process, but a product, or a concomitant, of attention. Psychologically they are alike untrustworthy, in so far as they neglect the record of introspection by the subject in regard to the state of his attention or the distinctness of what he is attending to. None of them provides a sufficiently reliable measure by which the attention of an individual may be compared at different times, or with the attention of other individuals. A fourth method, for which greater promise has been claimed, consists in determining by numerous experiments the various strengths of a distracting stimulus necessary for producing definite amounts of deterioration in the efficiency with which the subject executes a given task; and in correlating the effects of such distracting stimuli with the introspective data afforded by the subject.

It is, however, doubtful whether attention in general is susceptible of measurement. This doubt involves a thorough-going inquiry into the fundamental nature of attention,—a problem into which we cannot enter here.

BIBLIOGRAPHY.

J. R. Angell and A. H. Pierce, "Experimental Researches on the Phenomena of Attention," *Amer. Journ. of Psychol.*, 1892, iv. 528. A. J. Hamlin, "On Least Observable Differences between Stimuli," *Amer. Journ. of Psychol.*, 1894, vi. 564. W. Heinrich, "Zur Erklärung d. Intensitätsschwan-

kungen ebenmerklicher opt. u. akust. Eindrücke," *Bullet. internat. de l'Acad. des Sciences de Cracovie*, 1898, 365 ; "De la Constance de Perception des Tons purs à la Limite de l'Audibilité," *ibid.*, 1900, 37. J. W. Slaughter, "The Fluctuations of the Attention in some of their Physiological Relations," *Amer. Journ. of Psychol.*, 1900, xii. 313. W. M'Dougall, "The Physiological Processes in the Attention Process," *Mind*, 1902 (N.S.), xi. 316 ; 1903 (N.S.), xii. 289, 473 ; 1906 (N.S.), xv. 329. W. Wirth, "Zur Theorie d. Bewusstseinsumfanges u. seiner Messung," *Philosoph. Stud.*, 1902, xx. 487. F. G. Bouser, "A Study of the Relations between Mental Activity and the Circulation of the Blood," *Psychol. Rev.*, 1903, x. 120. W. Wundt, *Grundzüge d. physiol. Psychol.*, Leipzig, 1903, iii. 67, 351. B. Hammer, "Zur experiment. Kritik. d. Theorie, d. Aufmerksamkeitsschwankungen," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1905, xxxvii. 363 ; *Ztsch. f. Psychol.*, 1906, xli. 48. W. Peters, "Aufmerksamkeit u. Zeitverschiebung in d. Auffassung disparater Sinnesreize," *Ztsch. f. Psychol. u. Physiol. d. Sinnesorgane*, 1905, xxxix. 401. C. E. Ferree, "An Experimental Examination of the Phenomena usually attributed to Fluctuations of the Attention," *Amer. Journ. of Psychol.*, 1906, xvii. 81 ; *ibid.*, 1908, xix. 58. W. B. Pillsbury, *Attention*, London, 1908.

CHAPTER XXV

ON FEELING[1]

The Determinants of Feeling.—The way in which any given presentation affects us is partly determined by the nature of that presentation. Certain odours, tastes, shapes, and situations, certain combinations of colour or of tone, seem inherently and almost universally pleasant, beautiful, exciting, comic, or the reverse, or indifferent.

We may roughly investigate this relation between the cognitive and the affective modes of consciousness, by taking into our consideration objects and situations which we experience in daily life; thus we may note the proportions of lines or the combinations of colours, which are preferred for everyday use. We may supplement this "method of observation" by a "method of production," in which subjects are asked to produce those proportions, combinations, or forms which they consider pleasant, beautiful, etc.

The broad relations thus shown to subsist between sensory (or ideal) presentation and feeling are by no means the sole determinants of the affective outcome of such a presentation. The total state of the subject has also to be taken into consideration,—his past education and experience, his proneness to suggestion and to adaptation, his present mood or train of thought, and other like factors. It is not sufficient to have determined statistically that a given stimulus, or rather its percept or idea, is pleasant, indifferent,

[1] The word is used very loosely as a convenient heading to this chapter.

or depressing. Investigations must be so planned as to examine alike the individual subjective, as well as the objective, determinants of feeling in an adequately psychological manner.

Experimental Procedure.—As in so many other themes of research in experimental psychology, investigations upon feeling have been for the most part confined to the use of simple objects. In experimental æsthetics, for example, rectangles, triangles, curved or straight lines, or simple combinations of colour, form the chief material that has as yet been used. The advantage of employing such simple objects lies, in the first place, in the fact that the æsthetic or other relations are simpler, and that introspection is proportionately easier; and, in the second place, in the fact that we can prepare a graded series of any particular variable. For instance, a series of equally graded shades of a given colour may be obtained; or a given line may be made to vary in length, in curvature, in inclination, or in thickness, or simultaneously in two or more of these directions.

Such changes in the object are usually effected by as many successively different exposures, but they may sometimes be effected continuously during a prolonged exposure. Thus by an arrangement similar to that described in experiment 141, a given object, *e.g.* a rectangle, or the body of a dachshund, may be gradually elongated or shortened. In these experiments the point of maximal feeling may be estimated by the method of production (page 202), or by the method of comparison, which we shall describe immediately.

When a series of objects, varying in one particular direction, has been prepared, they may be exhibited to the subject simultaneously or successively; they may be exhibited all together, singly, or in groups of two.

The Method of Choice.—When many of the objects are simultaneously exhibited, we employ the "choice" method.

The subject is asked to choose the object which most excites in him that feeling which is under investigation. It is a cruder method and obviously gives less valuable psychological information than either of the following.

The Method of Comparison.—This is a method of paired exposures, the members of each pair being exhibited successively or simultaneously, and the subject comparing the degree of feeling produced by each. It is really only a modification of the constant method (page 210). One member of each pair is the constant or standard throughout a given number of paired exposures, while the other is variable.

When the members of each pair are simultaneously exposed, the so-called space error may be measured; when they are successively exposed, both the space and the time errors may be determined. The subject's answers may be graded thus—"much pleasanter," "pleasanter," "doubtful," "indifferent," "more unpleasant," "much more unpleasant"; or other variations may be introduced which were suggested when we were describing the constant method.

The standard may remain the same throughout different groups of experiments repeated at different times. In this case the standard should be one which is known to excite only a moderate degree of the feeling under investigation. Or the standard may be systematically varied in different groups. Thus, if a series of graded objects be denoted by the letters A, B, C, D, . . . K, the first experiment may consist of the standard A simultaneously presented with B, then with C, then with D, etc.; in the second experiment B will be standard, and will be presented with A, C, D, etc.; in the third experiment C becomes the standard, and is successively presented along with A, B, D, etc.; and so on until each member of the series has been in turn a standard. A second series of experiments may be repeated in inverse order, K being the first, and A the last used standard. Thereupon a third and fourth series should be obtained, in which the standard lies on the opposite side of

the variable to that which it had occupied in the previous two series.

The Method of Single Exposures.—In this method, often called the "serial method," the objects are shown singly in regular or irregular order, and the judgments of the subject are absolute instead of relative. They may be recorded thus—"very beautiful," "beautiful," "doubtful," "indifferent," "ugly," "very ugly." This method serves as a valuable control over the method of comparison. For when two objects A and B are compared, although A may be liked better than B, yet absolutely (apart from its relation to B) the subject may be indifferent to it, or may even dislike it.

The Influence of Association.—An important advantage obtained by the use of simple objects consists, as we have already said, in the facilitation of introspection. The simpler the object, the more readily can the subject determine the content of consciousness and the degree to which his feelings are influenced by the object itself or by the associated experiences which the object arouses. The individual differences that have been experimentally demonstrated, both as regards the degree of feeling and the nature and number of associated experiences directly or indirectly aroused by the object, are astonishingly great. A given oblong figure, for example, may be preferred by a subject because its shape suggests that of a room which is full of pleasant associations; or a uniform field of colour may appear unpleasant because it suggests the dress of some person who is disliked. In some cases, at least, these diverse effects of association become less obtrusive as the subject becomes accustomed to the experiments, until finally the feelings directly attached to the simple objects which are exposed to him are free from disturbance and open to examination. In other individuals, such associations play little or no part in their preferences. They like a colour because subjectively it is warm, stimulating, or

soothing; or because objectively it is a "pure" colour. Others, again, are found to treat the colour as if it were a living subject. They dislike it because it is unfriendly or dishonest, or like it on account of its frankness or joviality.

The Duration of Exposure.—The effect of duration of exposure upon the feeling aroused by an object is capable of experimental investigation. It is usually found that up to a certain length of exposure the feeling grows in degree, but that with longer exposures this no longer holds, the character of the feeling changing, and a previously pleasing experience even becoming displeasing.

Æsthetic effects have been obtained even with very short exposures, during which, it may perhaps be assumed, the subject has no opportunity of, so to speak, "living into" the experience. Doubtless with longer exposures, this factor of "empathy,"[1] as Lipps insists, plays an important part. The subject feels in himself the suggestions of strain, movement, or rest in the object, and makes them part of himself (page 302). The æsthetic value of the object depends much on the nature of these suggestions. By further modifications in experiment, and by appeals to introspection, we may hope to examine the truth of other theories that have been advanced.

It remains for future experimental investigation to determine the precise effects of simultaneous and successive contrast of feeling, and the effects of summation and compensation of feelings. A beginning has been already made. Individual differences, too, have been investigated with regard to the uniformity of judgments on different days, the effect of previously exposed objects, and the influence of past occupation and past judgments on present feeling. Into these and other results it is impossible here to enter. They may be regarded as pioneer work paving the way to more extended observations.

[1] Professor James Ward suggests to me this convenient translation of the German *Einfühlung*.

The Motor Manifestations.—Experimental psychology has long devoted itself to analysing the movements whereby feelings gain expression, and to determining what relation exists between the various feelings and their accompanying movements.

These movements may be broadly classed as organic and skeletal; the former being carried out by the muscles of the abdominal and thoracic viscera and by the blood vessels, the latter by the voluntary muscles of the body.

Organic Movements.—Changes in the rate and depth of respirations may be readily studied by means of the pneumograph (exp. 151); changes in the rate and force of the heart beat by applying the sphygmograph to the pulse (exp. 152), or the plethysmograph to a limb (exp. 153); changes in the volume of a limb, due to changes in the heart beat, or to active dilatation or constriction of the blood vessels, are revealed by the plethysmograph; changes in the blood pressure by the sphygmograph, the plethysmograph, or the sphygmomanometer.

Attempts have been made to reduce experimental conditions to the utmost simplicity by blindfolding the subject, enjoining him to cultivate a state of reverie, and then applying a sensory stimulus which is calculated to produce in him a definite change of feeling. The organic movements which are set up in the subject are carefully noted by the experimenter, who correlates them with the changes in feeling to which the stimulus has given rise.

As a general rule, a pleasant stimulus, *e.g.* a pleasant odour or sound, causes an increased volume of the limb as determined by the plethysmograph. This rise in volume is usually preceded by an initial fall. Unpleasant stimuli produce a simple fall in volume. The respiratory changes are found to vary widely in different individuals. Pleasant tastes quicken the pulse and raise its height, the increase being most evident in the case of very faintly pleasant stimuli. Pleasant tones and colours, on the other hand,

are said to slow the pulse. According to some observers, the pulse wave diminishes in height and in length when the stimulus is unpleasant. But according to others, the pulse almost invariably quickens with the exhibition of unpleasant stimuli, its frequency increasing with the degree of unpleasantness. We shall later recall attention to this divergence between the results obtained by different investigators and from different subjects.

While the subject is attending to an easy task, his pulse is unchanged or becomes slower, and his respirations grow shallower. But in strained attention, the pulse always quickens, its force and the volume of the arm diminish, while the changes in breathing vary according to the individual. If, during such a state of tension, either a pleasant or an unpleasant stimulus be exhibited to the subject, the pulse always slows; in other words, the signs of relaxed attention replace those of pleasure or displeasure, although the feelings of pleasure or displeasure are nevertheless present.

There is much other experimental evidence which shows how dependent the organic changes, that accompany a change of feeling, are upon the nature of previous or simultaneous affective states. Thus it appears that, while unpleasant stimuli are accompanied by a diminution, and while expectation is accompanied by an increase in the volume of the arm, the latter may remain unchanged when expectation and unpleasantness coexist.

Sensations of pain quicken the rate of the pulse and usually that of respiration. The pulse is slowed in joy and grief, when accompanied by excitement and expectation; the latter quicken the pulse. At the very onset of fear, the pulse is said to increase in force and to diminish in rate.

Skeletal Movements.—Similar simple methods of experiment have been applied to determine the effects of changes of feeling upon the contraction of skeletal muscles. For this purpose the muscles of the limbs have been examined

both in the relaxed and in the contracted state. In experiments on relaxed muscles, the arm is supported comfortably upon an apparatus that resembles the planchette, capable, that is, of recording the slightest movement involuntarily imparted to it by the arm (exp. 154). Some observers have found that pleasant and unpleasant stimuli unconsciously produce movements of extension and flexion respectively. It is asserted, however, that in certain individuals precisely the opposite relation exists.

The effect of such stimuli upon already contracted muscles may be investigated by observing the record of a dynamometer, which is grasped as forcibly as possible by the muscles under investigation, in the presence or in the absence of various stimuli (exp. 155). In place of the ordinary dynamometer a spring balance may be used. This is suspended vertically and is pulled upon by two fingers of the comfortably supported limb. The movements of the index of the balance may be easily transferred, by means of cords, pulleys, and levers, to a travelling smoked surface. The record obtained under ordinary conditions, when the blindfold subject tries, say for a minute, to maintain a state of maximal contraction is an obliquely descending almost unbroken line. When, however, a stimulus is exhibited to the subject, during this experiment, the record is altered according to the feeling produced. A very pleasant stimulus usually causes an initial drop followed by a significant rise in the tracing; after which the tracing gradually falls, though maintaining a higher level than usual. A very unpleasant stimulus, on the other hand, causes a decided fall in the tracing, after which there is a gradual fall, the tracing maintaining a lower level than usual.

The initial drop occurs both with pleasant and unpleasant stimuli, and with stimuli which are of indifferent character. But while in the first and last cases it is transient and is perhaps due to a distraction of the subject's attention, in the second not only is the effect more

marked, but it persists to some extent as long as the unpleasantness remains.

Attempts have been made to determine whether any relation exists between the appreciation of beauty in the form of an object and the eye movements which take place during regard of it. The eye movements have been recorded by photographic methods, and the results have shown that the æsthetic value of curved outlines bears no relation to the movement of the eyes as they wander over the figure. In regarding a beautiful vase, the eyes do not follow its sinuous contour, but they move irregularly in zigzag fashion over the surface of the object.

The Relation between Feelings and their Expression.— The interpretation of these investigations of the relation between feelings and their expression has been often coloured by the preconceived theories held by the investigators. We may recall the fact that Wundt, analysing certain records, discovers in them evidence that all feelings may be resolved in the directions of pleasure or displeasure, excitement or depression, strain or relief; that Royce would substitute for this tri-dimensional theory a bi-dimensional theory of feeling, comprising pleasantness or unpleasantness, and restlessness or quiescence; while Titchener insists that all such "feelings," save pleasantness and unpleasantness, can be reduced to sensorial experience in terms of kinæsthesis or general sensibility (cœnæsthesis), and that pleasantness and unpleasantness are the sole elements of feeling.

Whatever be our limitation or definition of feeling, we have sufficient evidence to indicate that pleasure and displeasure are independent of afferent impulses derived from organic or skeletal movements. No circulatory, respiratory, or visceral disturbances have been hitherto identified as being indispensable concomitants of pleasure and displeasure. On the contrary, we have shown (page 333) that pleasure and displeasure may exist in the absence of such changes.

Nevertheless we must regard the various organic and skeletal movements, which we have described, as closely associated with the presence of the states of pleasure or displeasure themselves. For when a subject has been anæsthetised by laughing gas, the organic movements which would normally be produced by pleasant or unpleasant stimuli do not occur; and in partial anæsthesia, the movements vary in degree with the depth of the anæsthesia. They have been produced during hypnosis by suggestion of the appropriate feeling.

Accordingly, we may consider the organic and skeletal movements not as determinants of the degree of pleasure and displeasure, but rather as the outcome of those central changes (producing excitement, effort, or strain) which accompany and follow pleasure or displeasure. The sensory impulses, derived from such movements, doubtless reinforce the central changes in question. Adopting this view, we may with far greater probability refer the influence, which a pleasant, indifferent, or unpleasant stimulus has upon muscular effort, to changes in central excitement or strain rather than to the pleasant, indifferent, or unpleasant feeling to which it gives rise.

We regard pleasure, indifference, and displeasure as psychical attributes of all states of consciousness, whether predominantly intellectual, conative, or affective, while we regard involuntary movement as especially, although not solely, characteristic of affective states. As to the time relation between affection and the organic and other movements, it is extremely difficult to obtain satisfactory experimental evidence. The results of different investigators are hopelessly discordant, and until these and other results are in better agreement, it is impossible to consider their relevance to the James-Lange theory, which identifies emotion with organic sensation.

BIBLIOGRAPHY.

T. Fechner, *Vorschule der Æsthetik*, Leipzig, 1876, i. C. Féré, *Sensation et Mouvement*, Paris, 1889, 1900. A. Lehmann, *Die körperlichen Äusserungen psychischer Zustände* (deutsche Uebersetz.), Leipzig, Tle. 1, 2, 1899, 1901. Larguier des Bancels, "Les Méthodes de l'Esthétique expérimentale," *L'Année psychol.*, 6me Année, 1900, 144. G. M. Stratton, "Eye-movements and the Æsthetics of Visual Form," *Philosoph. Stud.*, 1902, xx. 336. P. Zoneff u. E. Meumann, "Ueber Begleiterscheinungen psychischer Vorgänge in Atem u. Puls," *Philosoph. Stud.*, 1902, xviii. 45. H. C. Stevens, "A Plethysmographic Study of Attention," *Amer. Journ. of Psychol.*, 1905, xvi. 409. K. Gordon, "Ueber das Gedächtniss für affektiv bestimmte Eindrücke," *Arch. f. d. ges. Psychol.*, 1905, iv. 437. M. Kelchner, "Die Abhängigkeit d. Atem- u. Pulsveränderung vom Reiz u. vom Gefühl, *ibid.*, 1905, v. 1. L. J. Martin, "An Experimental Study of Fechner's Principles of Æsthetics," *Psychol. Rev.*, 1906, xiii. 142. P. Souriau, "Révue d'Esthétique," *L'Année psychol.*, 12me Année, 1906, 406. O. Külpe, "Der gegenwärtige Stand. d. experimentellen Ästhetik," *Bericht über d. II. Kongress f. experim. Psychol.*, Leipzig, 1907, 1. E. Bullough, "On the Apparent Heaviness of Colours," *Brit. Journ. of Psychol.*, 1906–8, ii. 111; "On the 'Perceptive Problem' in the Æsthetic Appreciation of Single Colours," *ibid.*, 406. F. Peterson and C. G. Jung, "Psycho-physical Investigations with the Galvanometer and Pneumograph, etc.," *Brain*, 1907, xxx. 153. E. B. Titchener, *The Psychology of Feeling and Attention*, New York, 1908.

LABORATORY EXERCISES

FOREWORD

Most of the following exercises require the co-operation of two students, one of whom, the "experimenter," conducts the experiment upon the other, who is called the "subject." It will be found advisable that the same pairs of students should work together through a fairly long series of exercises, rather than that the pairs be changed at each meeting of the class. Experimenter and subject thus get to work together with the desired smoothness. On the other hand, an occasional change has the great advantage of impressing on the students the enormous individual differences met with in different subjects.

The members of each pair should reverse places in successive experiments. It is important that at the outset students should realise the equal importance of the rôles of subject and experimenter. A detailed record of the mode in which an experiment has been carried out, and of the data which have been obtained by the experimenter, is psychologically almost valueless unless it be accompanied by a correspondingly ample introspective record on the part of the subject. The subject should be encouraged to take note of every introspective detail, however trifling it appear. In some experiments it will be found convenient for the subject to dictate the results of his introspection to the experimenter, who writes them down. But better results will usually be gained when the experiment permits of the subject himself recording these data, either as they occur, or shortly after, during a break in the experiment.

Every experiment should be carefully written out at home from the data obtained in the laboratory. The notebooks of experimenter and subject should tally, each incorporating the other's data, so as to give a complete account of the same experiment. The state of his notebook affords by far the best evidence of the student's diligence and ability.

It need scarcely be said that the success of an experiment depends much on the harmonious working of subject and experimenter. The

sooner an uncongenial pair of workers dissolves partnership, the better.

Those who desire a more elaborate account of laboratory practice should consult the *Experimental Psychology* (4 vols., New York, 1901–5) of Professor E. B. Titchener. No writer on the subject can escape laying himself under a debt of obligation to this work. The *Course of Experimental Psychology*, by Professor E. C. Sanford (Boston, 1897–8), although covering less ground, can also be warmly recommended. But many of the experiments following are not given in either of these books.

EXERCISES ON CHAPTER II

Cutaneous and Visceral Sensations

Temperature Spots.

Exp. 1. The student should first gain a general idea of the character of the sensations produced by the stimulation of cold and heat spots. Let him successively and lightly touch neighbouring points of the skin of his hand or arm with a pencil or other cold round-pointed object, and observe how sensations of cold flash out from time to time. A round-pointed metal object, warmed in water or in the flame to a not uncomfortable temperature, is to be similarly moved over the skin. The blunter and more diffuse character of the sensations produced by heat spots will be at once recognised.

The experimenter now proceeds to map out an area on the back of the subject's hand, measuring about 20 by 10 sq. mm. He then takes one of a number of metal cylinders which have been immersed in a vessel of cold water standing in freezing mixture.

Having dried the cylinder, the experimenter begins to explore the cold spots within the area above delimited. The subject sits with his eyes shut, and with his hand loosely closed and comfortably supported; he carefully notes his experiences and records them periodically. The exploration must be done in a systematic manner, the cylinder being methodically applied along an imaginary series of lines, 1 mm. apart, parallel to one of the sides of the square. Along these lines the cylinder is lightly applied to consecutive points; it is always moved in the same direction, and where the subject exclaims that he feels a pronounced cold sensation, the experimenter marks the position of the cold spot in coloured ink or dye upon the skin, by means of a finely

pointed brush. The experimenter occasionally puts back the cylinder into the cold water and takes up and dries a fresh one. When the area has been explored, point by point, in this way, the experimenter draws a similar area on two pieces of tracing paper, which he applies to the skin, marking in the cold spots in their proper position. One of these two records is for the subject's notebook, the other for the experimenter's.

Exp. 2. The heat spots are to be sought for in a similar way over the same area, after the previously marked dots have been removed. These spots are fewer and are more difficult to determine. The whole cylinder must be warmed in hot water until its temperature is tolerable (about 48° C.) without causing unpleasantness. In the course of the exploration the cylinder must be repeatedly warmed,—an inconvenience which may be reduced by using a more massive metal instrument, *e.g.* a finely pointed soldering iron. The heat spots are to be marked and their position is to be indicated, in dye or ink of another colour, upon the tracing paper used in the previous experiment.

Temperature spots, especially some of them, are very easily fatigued. Hence they must be left at rest before the area is re-investigated, in order to confirm previous explorations.

Exp. 3. Sometimes cold sensations occur during the search for heat spots. Having selected a few exceptionally sensitive cold spots, the experimenter taps one of them lightly with a very small round-pointed object, a bristle or a piece of wood. Into another he thrusts a thin, finely pointed needle. Upon a third he tries the effect of a heated (50° C.) point. He should similarly investigate the effect of touch, prick, and cold upon heat spots.

Touch Spots.

Exp. 4. A convenient set of instruments for demonstrating the existence of touch spots can be made by perpendicularly mounting hairs of different length and thickness, each at the end of a match. The pressure exerted by a hair depends chiefly on its length and thickness, and within wide limits is independent of the extent to which it is bent. This pressure may be measured in grams, by applying the end of the hair to one of the scales of a balance.

The experimenter carefully notes the points of emergence of all the hairs within the area of the subject's skin already delimited. He marks these points on the skin in ink and transfers them to a corresponding square of tracing paper, as before. A magnifying-glass should

be used to detect the finer, shorter, or fairer hairs. Then the hairs are cut off by fine scissors close to the skin surface, and the dots are washed away. (If the hairs were not cut off, it would be impossible to explore the cutaneous area satisfactorily. The hairs would frequently be touched by accident, and would as often stimulate the underlying touch spot.) The experimenter selects a mounted hair which provides a stimulus of suitable strength, and explores the area systematically by a series of steady touches as before, the long axis of the hair being always applied perpendicularly to the skin. A few preliminary experiments should be made to acquaint the subject with the peculiar sensation produced by a touch spot. Each touch spot is to be marked on the skin in coloured ink, and when the whole area has been explored, the dots are to be transferred to the paper square; their relation to the original position of the hairs, and their independence of the position of the temperature spots being noted. The subject should observe the variations in character of the sensation produced by touch spots of different sensitivity. He should note whether any other sensations than those of touch are simultaneously or subsequently produced, and he should observe the differences in accuracy of localisation and in the apparent depth of the sensations produced by the temperature and touch spots.

Pain Spots.

Exp. 5. Let the experimenter lightly touch the bent knuckle of a finger of the subject with a finely pointed object, *e.g.* a needle. It is easy to observe that at certain spots the distinctly localised touch sensation is followed, after an obvious interval, by a more radiating, ill-localised, and unpleasant sensation of pain.

Exp. 6. The experimenter should endeavour to discover pain spots in a small part of the hairless area already used in the previous experiment. Care must be taken that the needle never pierces the skin. For this reason it is preferable to use pointed horse hairs or bristles, the sensitivity of the pain spots being raised by a thorough softening of the skin with soap and warm water. The advantage of pointed hairs lies in the possibility of standardising their pressure (cf. exp. 4).

Exp. 7. The experimenter selects (*a*) a touch spot which has not a pain spot in its immediate neighbourhood, and (*b*) a pain spot which has not a touch spot in its immediate neighbourhood. He stimulates each of them, and observes that the double sensation of touch and pain obtained above is no longer present.

Exp. 8. The inside of the cheek is explored by the interrupted current from an induction coil, the subject satisfying himself as to the existence of a painless area.

Exp. 9. The hand is dipped into water at 50° C. The initial sensation of temperature preceding that of pain, is observed.

Relation of Extent to Intensity of Thermal Stimulation.

Exp. 10. If the entire hand be dipped into water at 25° C., and if one finger of the other hand be dipped into water which is a few degrees higher in temperature, it will be observed that within certain limits, increase of the extent of surface stimulated causes increase in the intensity of the temperature sensation. Similarly, water which is not uncomfortably warm to a small area of the body becomes intolerably painful when a larger surface is immersed.

N.B.—It will be observed that when the arm is immersed in water no sensation of pressure is produced save at the line of emergence of the arm from water. The student should consider any possible explanation of this observation.

Temperature Adaptation.

Exp. 11. The subject places a finger of one hand in water at 15° C., and the corresponding finger of the other in water at 35° C. He notes the gradual changes in sensation, and after a few minutes he transfers the two fingers to water at 25° C., observing the temperature sensations in each of the fingers.

N.B.—The student should consider how it is that there is a difference between the temperature sensations afforded by touching various objects, solid and liquid, rough and smooth, about the room; and why it is that the same room feels warmer after a walk on a windy day, than after a walk on a windless but equally cold day.

Fatigue of Temperature Sensations.

Exp. 12. The subject places the same two fingers respectively in water at 45° and 28° C., the latter representing approximately the normal temperature of the skin. After about fifteen seconds he removes the fingers to water at 10° C. How can the fact be explained that the coldness of the latter is at first less felt by the finger which had been previously immersed in the hotter water? The experiment may be varied by transposing the two vessels of water at 10° and 45° C.

Temperature After-Sensations.

Exp. 13. The subject places a cold coin (about 5° C.) on his palm or forehead for about half a minute, and observes the after-sensation following removal of the coin. Is it continuous throughout or ever intermittent? Does it differ in any way from the character of the cold sensation? Similarly, the subject observes the after-sensation following removal of a warm object. He should consider the bearing of the two experiments on Weber's and Hering's theories. He should then investigate the after-effects of a stimulus applied for two minutes and maintained at about 9° C.

Temperature and Weight Illusion.

Exp. 14. The subject compares the weights of two similar coins placed alternately on the palm (or forehead), the one coin having been previously cooled, the other having been warmed approximately to the temperature of the skin. It will be found that a similar illusion holds for objects which are above as well as for those which are below the skin temperature.

EXERCISES ON CHAPTERS III AND IV

Auditory Sensations

Sound Conduction.

Exp. 15. The foot of a vibrating tuning-fork, *c*′, is applied to the vertex of the head or to the teeth.[1] The tone reaches the ears by bone conduction. It is only when the membranes and ossicles of the middle ear are defective that a fork (of moderate pitch) is audible by bone conduction, when it is inaudible *viâ* the outer and middle ear. This should be verified by observing that after the tone of a fork, applied to the bone behind the ear (the mastoid process), has apparently ceased, the fork can again be heard if it be at once removed and held near the outer ear.

Exp. 16. A vibrating tuning-fork is held opposite one ear, at a distance from it exceeding the distance from one ear to the other.

[1] The student should make it a rule to touch the prongs of tuning-forks with the uncovered hand as rarely as possible. The warmth of the hand produces a diminution in pitch, and its moisture makes the forks very liable to rust.

When the tone has become too feeble to be audible, the fork is quickly brought close to the ear. It will of course be heard again. A finger is now *lightly* introduced into the opposite ear hole. The effects upon the tone that are produced by alternately withdrawing and reintroducing the finger, should be then observed.

N.B.—The fork is first held at a distance greater than that between the two ears, in order, so far as possible, to meet the objection that the subsequent effects obtained by the finger are dependent on the passage of the sound to the more distant ear through the external air. To account for the effects, the following facts must be borne in mind. Bone conduction of sounds occurs from one ear to the other (page 21). If a finger is lightly placed in one ear, it reflects the sound waves which are travelling from within outwards, thus preventing their escape and intensifying the auditory stimulation of that ear. A sound is localised in that ear which receives the stronger stimulus (page 288).

Resonance.

Exp. 17. The student should familiarise himself with the phenomena of resonance, by using a series of tuning-forks and resonators. He should identify the resonator which is attuned to vibrate to any particular fork. Having by means of a movable clamp, slightly mistuned a fork, he should note the corresponding alterations in reinforcement by the resonator.

Exp. 18. If the loud pedal of a pianoforte be pressed down (in order that the strings may be free to vibrate), the resonant effect of singing tones before it may be readily observed.

Exp. 19. The external meatus itself behaves as a resonator. One tone more than any other in the neighbourhood of f^{iv} will be found to have a piercing character. The pitch of this tone should be determined by means of a small whistle. The resonant effect of the meatus, thus discovered, may be changed by inserting a piece of rubber tubing about half an inch long into each ear.

Noise.

Exp. 20. As opportunity arises, the student should examine the character of different noises introspectively, noting their varying dissimilarity from tones, and endeavouring to detect their pitch. He should depress a great number of adjacent keys on the pianoforte simultaneously,—or still better, sound numerous adjacent tones on

a *Tonmesser* (fig. 25),—and observe the noisy character of the resulting experience. This instrument, once made by the firm of Appunn, and often called after the original maker, contains a series of small metal tongues M which are enclosed in a case and blown by a bellows. The tongues are so attuned that the several tones they emit differ only slightly (by one, two, or four vibrations) from one another. Each tongue can be sounded or silenced by pulling out or pushing in the stop S attached to it. When in use, the case is closed and mounted on a table containing the bellows, from which air enters the case at T.

The student should notice the effects of coughing or "clearing the

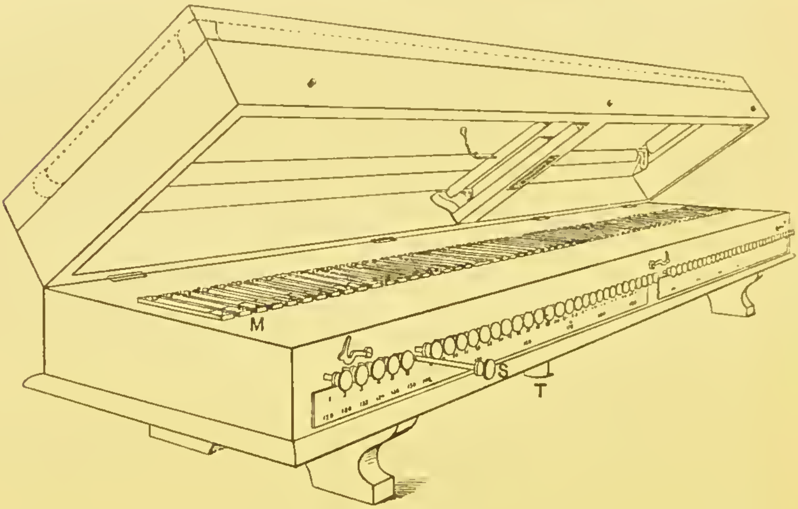

FIG. 25.

throat" before a pianoforte. The effect of practice upon the detection of pitch in noises is well shown by successively dropping wooden pencils of different length on to a wooden table.

TIMBRE.

Exp. 21. Tones of identical pitch should be produced from various instruments (strings, whistles, forks, metal tongues, sirens, etc.) in order that the inherent differences of timbre may be closely noticed. It is easy for the student to analyse the overtones by using the appropriate resonators. The pitch of the fundamental tone being known, he should calculate the pitch of the harmonic series of its overtones.

Exp. 22. The experimenter plucks the string of a monochord, and as its tone is dying away he touches it lightly with a small brush or feather at either of the points which trisects its length. He repeats this several times, the subject always listening carefully to the pitch of the tone produced by the brush. The experimenter touches the string with the brush each time more lightly than before. Ultimately, when the brush is not used at all and the vibrations of the string are allowed to die away undisturbed, the subject will distinctly recognise that overtone of the string, which has the same pitch as the tone produced by the brush. A similar procedure should be adopted in order to detect other overtones of the string.

N.B.—No special musical ability or previous training is required to observe many of these overtones successfully. After a little practice they may be detected in a prolonged note of the pianoforte. An attempt should be made to determine by introspection the effect of such analyses upon the character of the whole tonal experience.

Exp. 23. A fork and its octave fork, mounted on their respective resonance boxes, are simultaneously sounded. As the vibrations lessen the student notes the difference in timbre (comparable to a change of vowel in the voice) produced by stopping the vibrations of the higher fork.

After-Sensations.

Exp. 24. The experimenter suddenly stops the vibrations of a tuning-fork while it is held before the ear of the subject. The latter carefully observes whether he can recognise any after-sensations. If they are present, he endeavours to record their number, duration, character, and the interval elapsing between the removal of the stimulus and their first appearance.

Tone Character.

Exp. 25. The student should note the character of tones of different pitch.

The Intensity of Simultaneous Tones.

Exp. 26. A high fork and a low fork are simultaneously sounded upon their resonance cases, and their vibrations are allowed to die away until the high fork can no longer be heard. If now the vibrations of the low fork be stopped, the high fork will at once be heard again. On the other hand, if the sounds are allowed to continue until the low fork is no longer heard, the audibility of the latter will not be revived by stopping the higher fork. That is to say, a low

tone will obliterate a weak high tone far more completely than a high tone will obliterate a weak low tone.

The Upper Limit of Pitch.

Exp. 27. The upper limit of hearing is here determined by means of a Galton's whistle.

In blowing the instrument, care must be taken that the wind pressure employed be, as nearly as possible, uniform. The subject sits sideways at about a metre's distance from the experimenter. The latter takes the whistle and sets it so as to produce a relatively low tone. The whistle length is gradually shortened after each note is produced, until a point is reached when the subject can hear no tone, but only the puff of the windblast. The experimenter records the length of the whistle at this point, shortens it yet a little, and then commences a fresh series of observations, gradually lengthening the whistle until the subject just recognises the presence of a tone. Again the experimenter records the whistle length. Five pairs of such records should be taken, and the mean of the ten estimations be determined.

Binaural Differences in Pitch.

Exp. 28. The subject holds two tuning-forks of identical pitch, one in each hand, ready for the experimenter to strike them. The subject then lifts them several times alternately, the right-hand fork to the right ear, the left-hand fork to the left ear, and will perhaps ultimately decide that the two forks appear to be of different pitch. The experimenter applies a light clamp or a small lump of wax to the prongs of the apparently higher-sounding fork, and hands them to the observer. They are struck by the experimenter, and the observer again compares their tones. The clamp is raised or lowered until the tones appear identical.

N.B.—In seeking to account for the differences (if any) obtained, the student must bear in mind the various circumstances (pages 31, 32) in which an illusory change of pitch is possible.

Beat-Counting.

Exp. 29. The student simultaneously sounds the two forks, which have been brought to apparently identical pitch in the previous experiment. He proceeds to count the beats, aided, if necessary, by holding the two forks over a single resonator. Provided that the frequency of the beats do not exceed five per second, they may be counted directly. Beyond this limit, an intermediate fork must be

introduced, which is to be sounded first with one and then with the other fork, the beats being counted in each case. The beats are to be counted singly, or in pairs or in fours. Ten counts in all should be made, by different methods of reckoning, if possible. The counting must be begun when the position of the hand of the watch, as it lies exactly over a second's mark, coincides with a beat. The student must start thus: 0, 1, 2, 3, 4; he must remember to deduct one from the result if he start from unity. He should count for fifteen seconds, and then calculate the mean number of beats counted per second. Then he can express in terms of a fraction of a tone the difference between the two ears in the determinations of pitch.

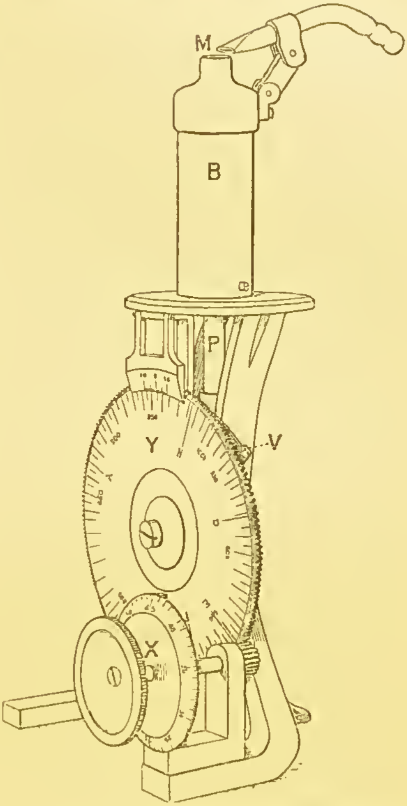

Fig. 26.—This instrument consists essentially of a bottle B which is blown at its mouth M. The column of air within the bottle is shortened or lengthened by the upward or downward movement of the piston P. The piston is moved by the rotation of a peculiarly shaped metal disc, the edge of which is just visible at V. The rotation of this disc (or "variator") is dependent on movement of the two connected graduated wheels Y and X, the latter of which, when manipulated by the experimenter, thus effects minute or relatively gross changes in the pitch of the note emitted by the bottle.

The Features of Beats.

Exp. 30. The four stages, alluded to on pp. 38, 39, should be observed as the frequency of beats is gradually increased. Two tuning forks giving c' may be employed, the pitch of one of which is gradually lowered by adjustable clamps. Stern's Tone Variators, however (fig. 26), provide a far more convenient apparatus.

Exp. 31. Beats obtained from different tone regions are to be compared.

A comparison is made, if possible, between the successive pairs of tones C_0 G_0, G_0 c^0, c^0 e^0, e^0 g^0, c' d', b' c'', each of which gives about 33 beats per second. The student should note the differences in roughness according to the tone region.

The Intertone.

Exp. 32. The pitch of the beating tone (the intertone) is carefully noted as the interval between two nearly identical tones is increased.

Difference Tones.

Exp. 33. The student takes two Quincke's tubes (fig. 27) of high pitch, *e.g.* c^{iv}, e^{iv}, giving an interval of a major third. He sounds them alternately in increasingly rapid succession, paying careful attention to the pitch of each note. Finally, while the lower tone is sounding, he introduces the higher. After a little practice he will be able to observe the deep difference tone and its peculiar localisation.

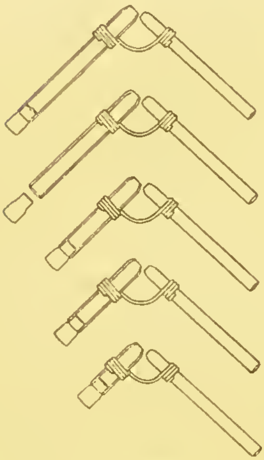

Fig. 27.

Exp. 34. The student simultaneously blows (if possible with a blast of regulated constant pressure) two ordinary piston whistles,—better still, two of Stern's Tone Variators (fig. 26),—starting from unison and gradually raising the pitch of one of them. At first only beats are heard; next, possibly the difference tone of the second order; later, the very low difference tone of the first order appears, which rises in pitch as the interval between the primary tones increases.

Exp. 35. The student takes two tuning-forks of known pitch, which give an audible difference tone of the first order. He sounds these on their resonance boxes and compares the pitch of the difference tone with that of a suitable simultaneously sounding fork, the tone of which can be varied by means of an adjustable clamp. Beats will be heard as the pitch of the latter fork is brought near to that of the difference tone, the beats becoming slower with diminishing difference of pitch and disappearing when absolute unison is reached. In order to determine the pitch of the difference tone, the pitch of the tone given by the fork thus clamped must be found by making it beat with another fork of known pitch.

Exp. 36. If two Quincke's tubes (with corks removed) which lie a major seventh apart (8 : 15) be sounded together, careful observation will reveal the presence of the deep difference tone of the second order lying three octaves below the lower tone.

THE RELATIONS OF TONES.

Exp. 37. The student should familiarise himself on the pianoforte with various intervals within and beyond the octave, playing the tones of each interval both successively and simultaneously, and using the same tonic (page 29) throughout. He should note the intimate relation of a tone to its octave, and the differences between the various consonant and dissonant intervals.

Exp. 38. The different degrees in which fusion is manifested may be easily studied if the experimenter sound sometimes two tones, and at other times only a single tone, the subject deciding whether one or two tones are present. The number of correct answers given by an unmusical subject varies with the degree of fusion. The ease of analysis of a given interval may be also examined when the latter is increased by one or more octaves.

EXERCISES ON CHAPTER V

Labyrinthine and Motor Sensations

Labyrinthine Sensations.

The experimental results recorded on pages 65-66 are readily capable of verification. A turntable is required for passive rotation.

Motor Sensations.

THE DISTINCTION BETWEEN CUTANEOUS AND MOTOR SENSATIONS.

Exp. 39. The motor sensations, which occur during the movements produced by faradic stimulation of appropriate points on the forearm, are observed.

PASSIVE MOVEMENT.

Exp. 40. The subject's arm is bared and supported in a comfortable resting position. His eyes are closed. The experimenter places on the forearm a weight; the base of which is covered with a pad of blotting paper, in order to reduce the conduction of heat from the skin. He leaves it there for several seconds. The subject records the various experiences which he obtains during and after the application of the weight. After allowing a sufficient interval of rest, the experi-

menter next applies a much heavier or lighter weight to the subject's arm, and a similar introspective record is obtained.

Exp. 41. The same experiment is performed while the skin is being rendered anæsthetic by spraying it with ether. The skin is sprayed for about half a minute, and then the weight is placed upon it for a few seconds. Thereupon the weight is removed and the spraying is recommenced. This alternation is continued until the skin is quite anæsthetic. Careful introspective records—and these are easily procurable after a little training—will yield interesting points of comparison with the records obtained in the previous experiment.

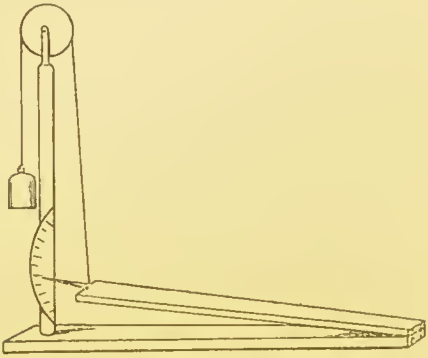

Fig. 28.

Exp. 42. The effects of passive movement may be roughly studied by means of the apparatus illustrated in figure 28. The subject's forearm is laid on the hinged board, which is moved by the experimenter pressing down the counterweight. It is easy to observe that sensations of tension precede those of movement, and that the latter may occur although the subject is unable to determine the direction of movement.

Experience of Resistance.

Exp. 43. A finger of the subject's hand is fitted with a band, to which is attached a thread carrying a weight. The subject, blindfolded, holds his arm horizontally away from the body, and proceeds slowly to lower the arm. Meanwhile the experimenter suddenly and noiselessly removes the weight. The subject will note the sensation of resistance and the tendency to upward movement of the limb. He should carefully record these and other experiences occurring during the experiment, and he should endeavour to interpret them in the light of his knowledge of motor sensations.

Estimation of Liminal and Supraliminal Movements.

Exp. 44. For accurately studying the limen or threshold of just perceptible active or passive movement in different joints,

apparatus must be so contrived as to permit of movement only in the joint which is under consideration. Thus, in studying the movement of a finger joint, the palm and the remaining fingers are steadied in a plaster mould, and are kept at rest by the pressure of cushions, while the other joints of the finger are securely fixed. Under such conditions, the finger may be passively moved by means of a finger-cap fitting on to the tip of the finger, a thread passing from this cap over a pulley and terminating in a (variable) weight. A lever may be attached to the thread and brought to bear on a travelling smoked surface, whereby the extent and speed of the movement of the finger, whether it be moved actively or passively, may be recorded.

Such an experiment is too complicated for class work. On the other hand, the apparatus for studying appreciation of differences in extent of movement may be of a quite simple character. A graduated ruler, to which a rider and a stop can be fixed, will indeed suffice. A more convenient form of the apparatus (fig. 29) consists of a little trolley T made to receive the finger at F. This trolley travels easily along rails laid upon a graduated board, which can be placed in any position. The subject, standing or seated conveniently before the apparatus with his eyes closed, places his finger in the trolley, and his arm executes actively or passively the desired movement. A string, pulley P, and weight may be attached to the trolley, so as to increase or decrease the necessary force of movement. The excursions of the trolley can be limited in either direction by the movable stops S′ S″.

With such an apparatus, the arm of a blindfold subject may be actively or passively moved to a known extent, from a known position, in a known direction, with a known speed. And after a known interval of time the subject, still blindfold, may be asked to make an apparently equally extensive movement, from the same, or from a different, original position of the arm, with the same or with the opposite arm, in the same or in a different direction, with the same or with a different speed: and the accuracy of his estimate is recorded. Or, after a known interval, the subject's arm may be passively moved in a pre-determined manner, and his judgment in comparing the extent of the two movements recorded. Or again, two such trolleys may be prepared, so that the effects and the comparison of simultaneous movements of the two arms may be investigated.

It is obvious that a great variety of psychological experiments can be performed in this simple way. But the conditions laid down in Chapter XV. must be scrupulously observed. The student

is therefore advised to postpone working for the present with this apparatus.

One defect of such an instrument is that it provides no means of insuring a constancy of the share which the different joints (*e.g.* the

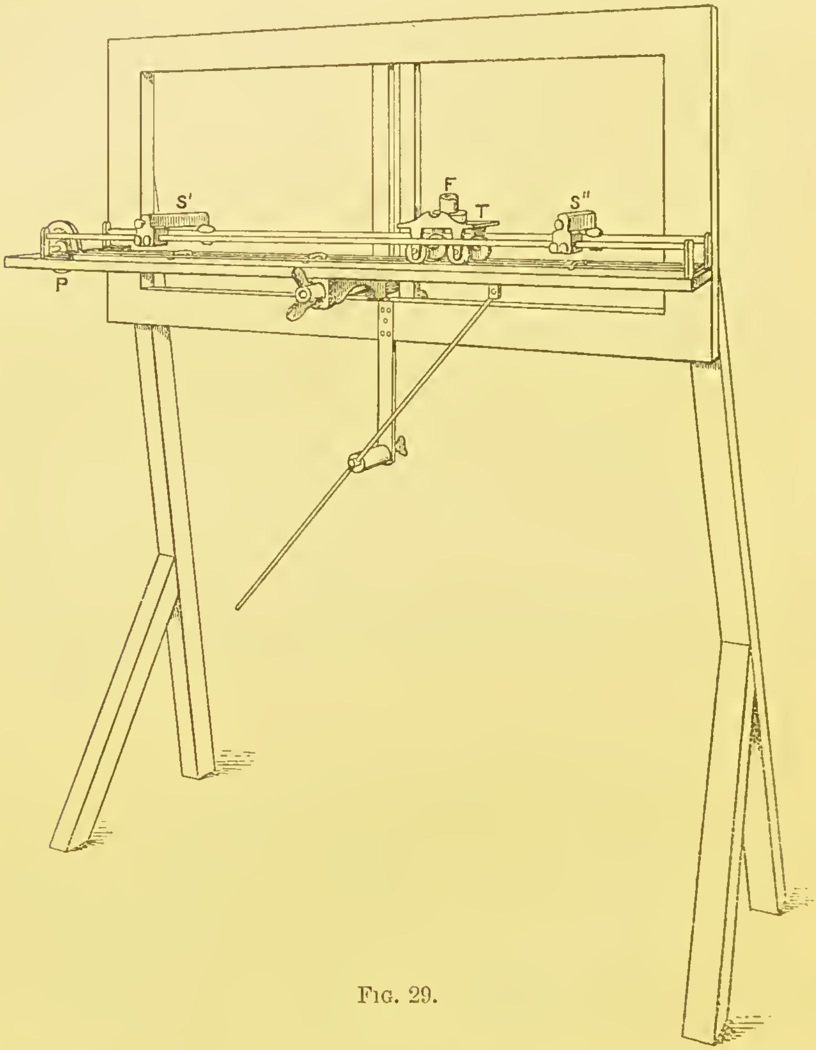

Fig. 29.

finger, the wrist, the elbow, and the shoulder) take in each total movement. Another objection is that it does not eliminate the complicating effects of sensations of cutaneous and deep pressure. With practice, however, a sufficiently uniform movement is attained. And it has the advantage of being a movement comparable to the movements made in everyday life.

EXERCISES ON CHAPTERS VI AND VII

Visual Sensations

THE CHARACTERS OF COLOURLESS AND COLOUR SENSATIONS.

Exp. 45. The series of colourless sensations obtained by varying the proportions of black and white upon the colour wheel (fig. 30) should be carefully observed.[1]

Exp. 46. The saturation of a colour is to be changed by mixing with it on the colour wheel varying amounts of white. The

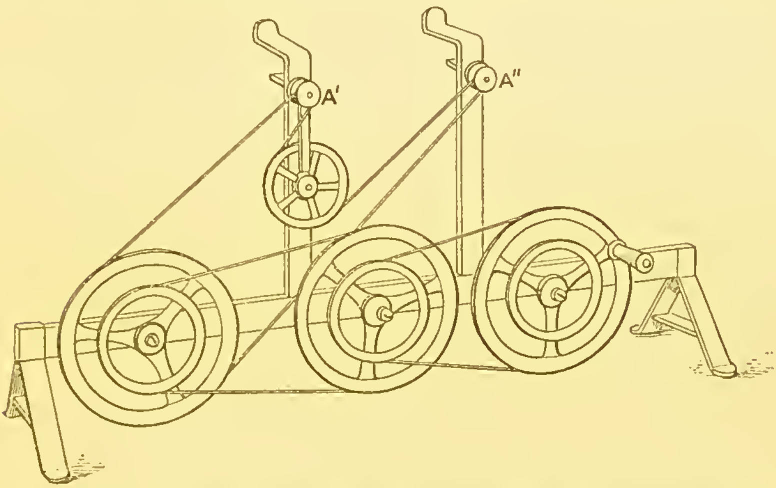

FIG. 30.—In the colour wheel here illustrated, the paper discs may be mounted both at A′ and at A″,—an arrangement which allows of the simultaneous exhibition and matching of two colour mixtures. In the more usual, simpler form of the colour wheel, the papers can be mounted on one axis only.

results of mixing colours with black should be also observed, and subsequently reconsidered in their relation to the theories of colour vision.

[1] When papers are mounted on the colour wheel, an *uncut* paper disc of the same diameter must always be placed behind them. Before the nut is screwed on, a minute disc of thick paper, having the same diameter as that of the nut, is interposed, in order to prevent the pressure of the latter from marking and wearing out the papers. Care must be taken to arrange the papers and to turn the colour wheel in a direction so that the free edges of the papers lie flat during rotation; otherwise, by flying up, they will become torn.

Exp. 47. The varying brightness of differently coloured papers should be noted. The degrees of brightness are to be determined by comparing them with papers of the colourless series. If the black-white values of the latter be known, the brightness of the various colours may be expressed in terms of these values; thus

$$Y = 178^\circ \, W + 182^\circ \, BK.$$

The student should be in a position to answer for himself the question, How may the saturation of a colour be changed upon the colour wheel, while its brightness remains unaltered?

Exp. 48. The observer sets up two squares of equally white papers at different distances from a window, one behind the other, so that when he looks at them with one eye directed through an open tube he obtains a circular plane field, filled half with the one and half with the other paper. Having set the papers at a distance from one another, which is just sufficient to obtain distinctly different degrees of brightness when they thus appear to be situated in the same plane, the observer removes the tube and compares the brightness of the papers in ordinary vision.

Exp. 49. Three spectral colours are to be chosen, so that when mixed in appropriate proportions on the colour wheel, they give rise to a colourless sensation.

The various hues, spectral and extra-spectral, obtained by mixing these colours in other proportions should be also noted.

Colour Mixtures.

Exp. 50. The observer finds the complementary colour to any colour, so that the two coloured papers, when turned simultaneously upon the same colour wheel, may give rise to a colourless sensation.

N.B.—It is at first puzzling to find that the blue and yellow papers, placed together on the colour wheel, produce a sensation different from that obtained by mixing blue and yellow pigments; but the explanation is easy. The papers are specially selected for their purity of colour, while ordinary blue and yellow pigments contain green, which becomes evident when the blue and yellow neutralise one another.

Exp. 51. Two small coloured paper squares of like dimensions are placed upon a black velvet ground. Between them is set a vertical piece of glass; and the head of the observer is so placed that the one colour, seen by light transmitted through the glass, and

the other, seen by light reflected from the glass, fall on the same area of the retina (fig. 31). The colour sensation thus produced should be compared with that obtained by the rotation of the same two colours on the colour wheel.

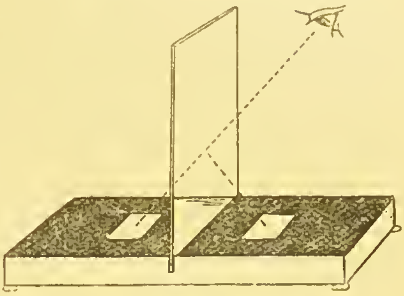
FIG. 31.

PERIPHERAL COLOUR VISION.

Exp. 52. The Perimeter enables the subject to demonstrate the regions of total and partial colour "blindness" towards the periphery of the retina, the experimenter moving towards the centre a small square of coloured paper along the free arm of the instrument. The experimenter selects such colours as orange, blue-green, or purple. He notes the points at which the colour just begins to be visible to the subject as a colourless spot. Within this zone he maps out another, in which the colour acquires a yellowish or bluish tinge. Finally, he defines the innermost area, in which the colour acquires a reddish or greenish tinge.

Under ordinary conditions the intermediate zone for yellow and that for blue vision are rarely quite coincident. But when care is taken that the two colours have equal chromatic and achromatic (*i.e.* brightness) values, the limits are identical. These conditions are satisfied when the two complementary coloured papers are so chosen that they require to be mixed in equal proportions to give rise to a colourless sensation, and that they are alike in size, brightness, and illumination.

An attempt should be made to find four colours which, as they are passed from the periphery over the retina, give rise (at first of course to colourless, and next) to colour sensations, the hue of which subsequently remains unaltered as the stimulus is moved still farther towards the fovea.

NEGATIVE IMAGES.

Exp. 53. A black square on a white ground is fixated for a few seconds. The eyes are then closed, or they are directed to a large, uniform grey or white surface. The observer should note (i.) the degree of brightness of the after-image of the square and of its background, (ii.) the series of reappearances of the after-image, (iii.) the degree of distinctness of the margins of the after-image of the square.

Exp. 54. He should next fixate a white square on a black ground, and obtain the after-image on a grey, white, or black surface, making observations as before. He should note whether the margins of the after-image of the square are as distinct as in the previous experiment, and whether the duration of original fixation affects the after-image and the breadth or brightness of the halo (sometimes called the "corona") which surrounds it.

Exp. 55. Similar after-images should be obtained from coloured squares upon colourless grounds. Coloured after-images should also be projected on squares of complementary or other colours. The after-image of a white square on a black ground should be projected on to an orange ground. The resulting experience should be remembered in considering later the nature of black.

Exp. 56. The blue-green after-image of a small red patch, fixated on a white background, is projected on to a black velvet background, and the brightness and saturation of this after-image is compared with that of a small blue-green patch lying on the black velvet a few millimetres away from the point of projection of the after-image. The student should consider later whether the results of the comparison are favourable to Helmholtz's theory of the cause of after-images.

Simultaneous Contrast.

Exp. 57. A disc containing a middle zone of black and white, surrounded by a given colour, is rotated on the colour wheel. The contrast colour is most marked when the coloured and colourless surfaces are of equal brightness.

Exp. 58. A grey paper is successively placed on different coloured backgrounds, which are equal to it in brightness. If the contrast effect is not apparent, it is immediately forthcoming when the grey surface and its adjoining background is covered with tissue paper. The contrast effect is reduced if a pencil line be now drawn on the tissue paper, corresponding to the margins of the underlying grey paper.

Exp. 59. The observer illuminates a white opal surface simultaneously with coloured light and with colourless light from two different sources. This can be easily effected by cutting two holes in the window-shutter of a dark room and by providing them

with adjustable screens of coloured and colourless glasses respectively, as in the annexed diagram (fig. 32). Between the sources of light and the opal surface an object, *e.g.* a vertically placed ruler, is interposed, so that two shadows of it are cast upon the opal surface, the one illuminated by the coloured, the other by the colourless light. A surprisingly intense contrast colour appears in the really colourless shadow, the intensity of the contrast varying with changes

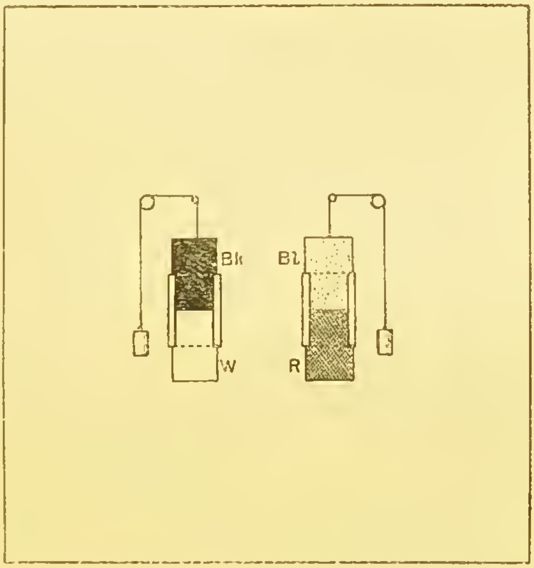

Fig. 32.

in the relative brightness in the two sources of light with which the white surface is illuminated.

Exp. 60. A point is fixated on a black surface between two red strips, which are about 10 mm. apart. The after-images are projected on to another black surface. The observer should compare the effects of projection on to grey and white surfaces, and the effects of laying the original strips on a grey or a white instead of on a black surface. He should consider what theoretical explanations of these effects can be advanced.

Exp. 61. Pieces of the same grey paper are to be placed on colourless backgrounds of different brightness. The observer notes the production of brightness contrast. He should consider how the effects of changes in the pupil can be eliminated, and whether the ontrast increases or diminishes upon fixation.

Exp. 62. A circular hole about $1\frac{1}{2}$ inches in diameter is cut in a large white card, which is held in a horizontal position. The observer gazes through the hole on to a sheet of colourless or coloured paper placed on a table near the window. He observes the alterations in brightness of the underlying paper (*e.g.* blue or orange), which are obtained by varying the inclination of the white card.

Exp. 63. A point is fixated on the margin between two adjoining black and white surfaces. On each surface, near the common margin, a short strip of darkish grey paper is laid. The observer notes the effect of simultaneous contrast and the changes which take place during continued fixation of the point (cf. exp. 74). He should also pay attention to the relative brightness of the two strips in the after-image, bearing in mind the theories of contrast.

Colour Blindness.

Exp. 64. A subject may be most easily tested for colour blindness by means of Holmgren's wools, provided that the following cautions be observed. The experimenter must never mention the name of a wool; he gives the test wool to the subject, merely asking him to select wools of similar colour. The experimenter observes not only the wools which the subject finally selects, but also those which he from time to time takes up and rejects. Both highly and lowly saturated wools should be employed.

Colour-blind people may elude detection by their familiarity with colour nomenclature. They come to recognise colours to which they are really blind by differences in saturation and in brightness. Cases of anomalous colour vision without absolute blindness may be detected by the above method.

The following matches have been actually made for red, yellow, blue, and green by colour-blind people. Paper discs, corresponding to the right-hand side of these equations, should be rotated on the colour-wheel by the student—

Scoteythrous class . . .	R = 18° Y + 342° Bk
Photerythrous „ . . .	R = 102° Y + 258° Bk
Totally colour-blind . .	$\begin{cases} R = 5°W + 355° Bk \\ Y = 136°W + 224° Bk \\ G = 152°W + 208° Bk \\ B = 88°W + 272° Bk \end{cases}$

Flicker.

Exp. 65. The observer notes the phenomena which attend the gradual extinction of flicker, as a white sector on a black ground is rotated with increasing speed upon the colour wheel. He should look for Charpentier's bands, Fechner's colours (apparent with bright illumination), the coarse flicker, the glitter, the fine flicker, and the finally complete fusion of sensations.

Exp. 66. A card of black and white sectors, arranged as in fig. 33 to illustrate the Talbot-Plateau Law, is rotated on the colour-

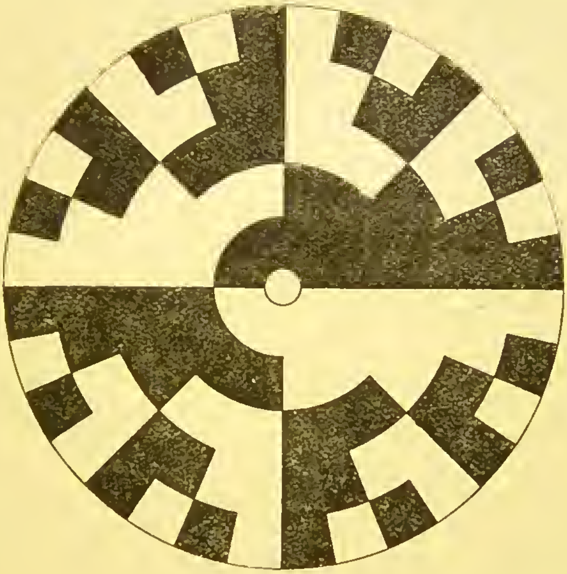

Fig. 33.

wheel. The various rings will be found to assume the same grey.

Estimations of Brightness.

Exp. 67. The brightness of a colour is to be measured by finding a grey background on which it becomes invisible when seen by the peripheral retina. For this purpose the subject fixes his eye on a spot marked upon a large black surface. The experimenter introduces a coloured disc (best mounted on an iron rod), moving it along the black surface until it is seen by the subject as a colourless field. Then various shades of grey are presented at this point along with

the colour stimulus, until a grey is formed the brightness of which appears to be uniform with that of the colour.

This determination is to be compared with the estimation of brightness obtained by direct comparison. The student should consider what relative effects the Purkinje phenomenon would produce in the two methods.

Exp. 68. A semicircle of grey, and one of a colour the brightness of which is to be tested, are arranged so that they form a circular

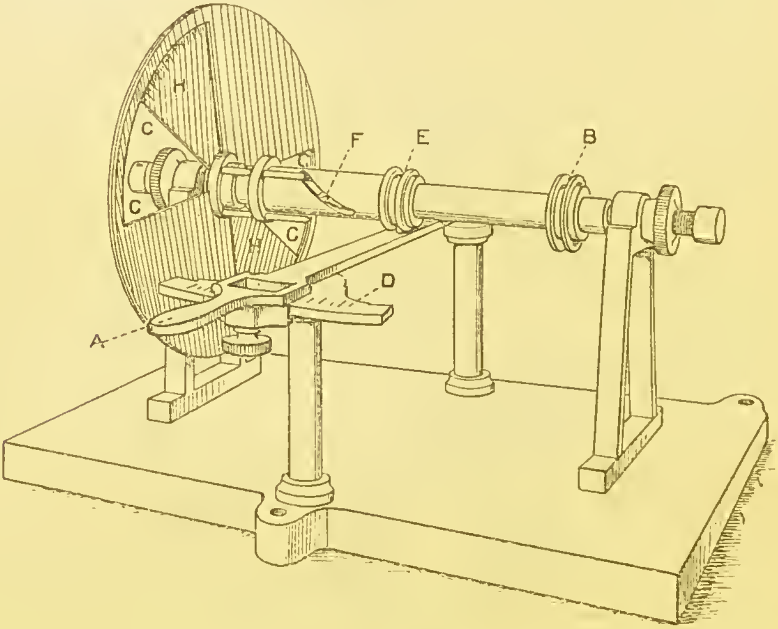

Fig. 34.—An Episcotister.

The width of the two open sectors C C, C C, can be varied by adjusting the sliding graduated plates H, H. These plates are moved by the arm A, which is movable along the graduated scale D. The action of the arm A is to slide the rim E, and the outer tube of which it forms part, round the projecting screw F. The sectors are rotated by a reliable motor, a belt from which passes over B.

vertical field. A disc composed of alternate open and closed sectors (fig. 34) is then rotated by means of a motor before this field. The observer notes whether flicker is abolished in the coloured or colourless halves of the field at the same moment. He replaces the grey by other shades of grey until flicker disappears in both halves of the circle simultaneously. Once again he compares his results with the two previous methods.

THE INTRINSIC LIGHT OF THE RETINA. DARK ADAPTATION.

Exp. 69. The gradual effects of dark-adaptation by entering a dark room should be carefully noted. In absolute darkness only the intrinsic light of the cerebro-retinal system remains. The nature of this light and the details occurring therein must be carefully studied. When the darkness is less complete and the eye has become dark adapted, the changes in relative brightness of different colours are readily noticeable.

Exp. 70. The observer determines, in bright light, the value of the grey which results from rotating fields of yellow and blue on the colour wheel, by matching it with a grey produced by the rotation of black and white discs on another colour wheel. Under like conditions, he determines the grey value from a similar fusion of red and green fields. He observes what alterations occur in these two matches when they are viewed in twilight by the dark-adapted eye.

Exp. 71. The observer notes whether differences in brightness exist in the case of two small squares of the same coloured paper, one being fixated at the fovea, the other stimulating the peripheral retina; first when the eye is bright adapted, secondly when the eye is dark adapted.

FIG. 35.

COLOURED WANING OF AFTER-IMAGE.

Exp. 72. The positive after-image which follows the extinction of a bright light is carefully noted, together with the play of colours through which the waning image passes. The observer should note in what respects, besides in hue and brightness, it differs from the negative after-image.

Exp. 73. The colours obtained by spinning Benham's top (fig. 35) are observed. The spinning disc consists of black lines on a white ground. The colours obtained probably have an origin similar to that of Fechner's colours and the coloured waning of the positive after-image.

SIMULTANEOUS AND SUCCESSIVE INDUCTION.

Exp. 74. A black square on a white background is carefully fixated by the aid of a central white dot. The black becomes brighter,

the white darker: ultimately both merge into a uniform grey (the "simultaneous induction" of Hering). The observer repeats this experiment, using colourless and coloured squares on colourless backgrounds of different brightness. He notes the effects in the after-image (the "successive induction" of Hering).

EXERCISES ON CHAPTER VIII

Gustatory Sensations

Reactions of Individual Papillæ.

Exp. 75. The experimenter makes a rough outline of the subject's tongue, sketching in any striking landmarks (ridges, etc.) which will serve to locate individual papillæ. He selects six prominent, easily identifiable papillæ, preferably in different situations, and notes their position on the map of the tongue.

He dries the subject's tongue with a piece of cloth or cotton wool, and investigates the reaction of these papillæ to distilled water and to sweet, bitter, salt, and sour solutions. The solutions are to be applied by means of fine brushes, which are kept in water and are dried before being dipped in the solutions. A lens should be used by the experimenter in order to insure exact application to the papillæ. The experimenter lightly applies the brush to the papilla for two seconds. The subject does not withdraw his tongue until he has an answer ready. The papillæ are tested, and the solutions are employed, in irregular order. A brief rest, preceded by rinsing the mouth, follows each application of the brush.

Record is made of (i.) the time elapsing between application of the stimulus and development of the sensation, (ii.) the duration of the sensation, (iii.) the nature of the sensation, (iv.) any changes in its character.

Exp. 76. The experimenter paints a papilla, which is sensitive to all four tastes, with a 10 per cent. solution of cocaine. He tests it with taste solutions, repeating the painting and testing until no further effect is obtained.

N.B.—Care must be taken not to apply cocaine to a wide surface of the subject's tongue, as some individuals are peculiarly susceptible to the dangerous effects of too much cocaine.

Exp. 77. After the subject has chewed some gymnema leaves, or after an already tested papilla has been painted with a solution of

gymnemic acid, the experimenter again tests the reaction of the papilla.

Mixture, Compensation and Rivalry.

Exp. 78. Two different taste solutions are mixed and applied to a papilla which is sensitive to the two tastes. Both weak and strong solutions should be tested, and the presence of compensation, rivalry, or of an altogether new sensation, be investigated.

Contrast.

Exp. 79. Having dried the subject's tongue, the experimenter applies to one side of it two drops of a taste solution of the nature of which the subject must be quite ignorant. The solution must at first be so weak that the tasting substance is incapable of stimulating the end organs. It is applied to the tongue by means of a finely pointed glass tube. The solution is to be increased in strength until with successive applications the subject gives correct replies. The subject continues to hold out his tongue after every application, until a taste sensation is developed or until the lapse of time has assured him that no sensation is likely to arise. In every case the experimenter notes down the subject's replies. The subject rinses his mouth with water when this part of the experiment is finished, and rests a while.

The experimenter now attempts to induce simultaneous contrast by applying to the opposite side of the subject's tongue two drops of a fairly strong solution of another taste (the inducing taste), while on the other side he applies drops of the taste solution previously used, starting, however, with pure distilled water and gradually increasing the strength of the tasting substance until its taste is recognised. The solutions should be dropped on the two sides of the tongue as nearly simultaneously as possible. Care must be taken that they do not mingle on the tongue.

The effects of successive contrast may be demonstrated by applying the inducing taste solution to the tip of the tongue. After two or three seconds the tongue is withdrawn and the mouth is well rinsed. The experimenter then applies distilled water or various strengths of a weak previously imperceptible taste solution to the same area.

Olfactory Sensations.

Classes of Smells.

Exp. 80. The subject should familiarise himself with the smells of odorous substances which are at his disposal. He should note

whether tactile, painful, thermal, or gustatory concomitants of the olfactory sensation are present in each case; and how far he agrees with Zwaardemaker's classification.

Respiration and Smell.

Exp. 81. The subject takes several rapid deep inspirations and expirations, so that he is subsequently able to hold his breath for about twenty seconds. As soon as he starts holding his breath he closes his eyes, and brings before the nose a bottle of strong ammonia or of spirits of camphor. He observes the pricking sensation and the entire absence of olfactory sensation. When the breath can no longer be held, he closes the nostrils with the fingers, removes the bottle, and takes ever so gentle an inspiration, observing the change in sensation.

Fatigue.

Exp. 82. The subject familiarises himself with the character and intensity of the odours of chlorine water, animal musk, copaiba balsam, heliotropin, and ether. He plugs one nostril with cotton wool and holds under the other a bottle containing spirits of camphor, or ammonium sulphide, or tincture of iodine. With eyes closed he continues smelling the bottle until the odour is no longer perceived. Then he examines the four odours above named and determines whether or not they have changed in character or intensity. He compares the different results according as the nose has been exposed to spirits of camphor, ammonium sulphide, or tincture of iodine.

Exp. 83. The subject should observe the gradual changes in sensation, as nitrobenzol, oil of camphor, or heliotropin is persistently smelled.

Mixture, Compensation, Rivalry.

Exp. 84. By using a double form of Zwaardemaker's Olfactometer (fig. 8), the effects of simultaneously presenting two odours to the nose may be accurately studied. For class purposes, however, it may suffice for the experimenter to take two bottles containing the odours and to pass them repeatedly in rapid succession before the nostrils while the subject is taking a slow prolonged inspiration. The subject must be already quite familiar with the separate odours, so that he may observe whether from time to time an altogether new sensation occurs when they are presented together.

EXERCISES ON CHAPTER X

Statistical Methods

THE MEAN, STANDARD DEVIATION, PROBABLE ERROR, ETC.

Exp. 85. The student is advised to work out their values for himself from the series of measurements given in the first of the following columns :—

v'	d	d^2	v''
190	−4	16	190
197	+3	9	190
196	+2	4	191
191	−3	9	191
195	+1	1	192
192	−2	4	194
194	0	0	195
196	+2	4	195
199	+5	25	196
190	−4	16	196
191	−3	9	196
196	+2	4	197
195	+1	1	199
13) 2522	13) 32	13) 102	
A = 194	*m.v.* 2·46	$\sigma^2=7{\cdot}846$	
		$\sigma=2{\cdot}8$	Mdn = 195.

In the first column the average is determined ; in the second, the mean variation ; and in the third, the standard deviation. The fourth column gives the values of v' in numerical order, showing the median at 195 and the quartiles at 191 and 196. Half the difference between the quartiles, namely, 2·5, gives the semi-interquartile range—a third measure of the variability of the series.

No mean is of any value unless it be accompanied by a figure expressing the variability of members of the series. But only one of these three measures of variability need ever be calculated for a given series. The most usual among psychologists is the mean variation. But it is less simple than the semi-interquartile range and less useful than the standard deviation, from which the probable error, E, of the mean may be determined by the formula—

$$E=\frac{0{\cdot}6745\,\sigma}{\sqrt{n}}.$$

N.B.—When the mean variation is being calculated, it is convenient to arrange the +, zero, and − values of d separately, thus :—

+ 3	0	− 4
+ 2		− 3
+ 1		− 2
+ 2		− 4
+ 5		− 3
+ 2		
+ 1		
+16		−16

The + and − values should be numerically equal, if the values of d and the mean have been correctly determined.

Exp. 86. The student should next calculate the mean, the standard deviation, and the probable error of the following series: 190, 198, 200, 192, 195, 200, 201, 195, 191, 194, 196, 199, 196. He can then determine the relation of the difference between this and the previous mean to the probable error of the difference between the means, in order to ascertain whether the difference is with any high degree of probability significant.

Correlation.

Exp. 87. The correlation between the following thirteen ($=n$) pairs of measurements, v_x, v_y, is here determined, the means of the two series being 194, 145 and their standard deviation 2·8, 3·4 respectively.

	v_x	v_y	x	y	xy
A	190	140	−4	−5	+20
B	197	150	+3	+5	+15
C	196	144	+2	−1	− 2
D	191	140	−3	−5	+15
E	195	144	+1	−1	− 1
F	192	148	−2	+3	− 6
G	194	146	0	+1	0
H	196	152	+2	+7	+14
I	199	146	+5	+1	+ 5
J	190	142	−4	−3	+12
K	191	143	−3	−2	+ 6
L	196	145	+2	0	0
M	195	145	+1	0	0
				$\Sigma(xy)=$	78

$$\text{Thus } \frac{\Sigma(xy)}{n\,\sigma_x\,\sigma_y}=0{\cdot}63.$$

By the simpler method (page 130) of giving orders of rank to A, B, C, etc., we have

	v_x	v_y	d	$(2d)^2$
A	$1\frac{1}{2}$	$1\frac{1}{2}$	0	0
B	12	12	0	0
C	10	$5\frac{1}{2}$	$4\frac{1}{2}$	81
D	$3\frac{1}{2}$	$1\frac{1}{2}$	2	16
E	$7\frac{1}{2}$	$5\frac{1}{2}$	2	16
F	5	11	6	144
G	6	$9\frac{1}{2}$	$3\frac{1}{2}$	49
H	10	13	3	36
I	13	$9\frac{1}{2}$	$3\frac{1}{2}$	49
J	$1\frac{1}{2}$	3	$1\frac{1}{2}$	9
K	$3\frac{1}{2}$	4	$1\frac{1}{2}$	1
L	10	$7\frac{1}{2}$	$2\frac{1}{2}$	25
M	$7\frac{1}{2}$	$7\frac{1}{2}$	0	——
			$\Sigma(2d)^2 = 426$	

When, as here happens, two or more individuals tie in rank, they are each given a figure intermediate between the ranks which they would occupy if they did not tie. To avoid squaring fractions, $2d$ has been squared instead of d. The fraction in the second of the alternative formulæ quoted on page 130 must therefore be divided by four. It thus runs :—

$$r = 1 - \frac{6\Sigma(2d)^2}{4n(n^2-1)}$$

whence $r = 0{\cdot}70$.

The discrepancy between the results of the two methods is unusually great in this particular case, and is partly due to the large number of tied cases.

N.B.—When the mean and standard deviations have to be calculated for long series, much time and labour may be saved by taking an approximately central variate (obtained merely by casual inspection of the series), and by subtracting each member of the series from this value. Let the algebraical sum of these several differences, divided by the number (n) of individual values, be represented by v_1. Then v_1, when added (with due regard of sign) to the assumed central value, will be found to give the average.

So, too, let the sum of the same differences, severally squared, be divided by the number of individual values, and let this sum be represented by v_2. Then $\sigma = \sqrt{v_2 - v_1{}^2}$.

Finally, if in two correlated series, $\Sigma(x^1 y^1)$ represent the sum of

the products of individual pairs of differences from the two central values (chosen as before), and if v_x, v_y, σ_x, σ_y represent the values of v_1 and σ in each series, then the formula for the coefficient of correlation becomes

$$\frac{\Sigma(x^1y^1) - n\ v_x\ v_y}{n\ \sigma_x\ \sigma_y}.$$

By such means a considerable saving in calculation is reached in determining the mean, the standard deviation, or the coefficient of correlation for lengthy series.

EXERCISES ON CHAPTER XI

Reaction Times

USE AND CONTROL OF THE APPARATUS.

Exp. 88. Reaction times are most conveniently and accurately determined by interruptions in an electric circuit; a current being "made" (or "broken") at the moment of exhibition of the stimulus, and being "broken" (or "made") by the response of the subject.

The response usually consists in lifting the finger from a Morse telegraphic key, or it may consist in lip movement or in vocalisation. For the two last modes of response a lip key or a voice key is used,

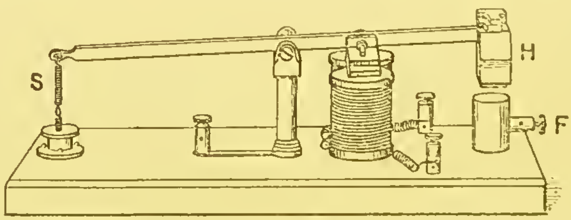

FIG. 36.

in which the electric current is broken by movements of the lip or by movements of a membrane thrown into vibration by the voice.

The appliances by which the current may be made (or broken) at the moment of exhibition of the stimulus are of various kinds, depending on the nature of the stimulus. The simplest available apparatus is a Morse key, which, when sharply and suddenly pressed upon, serves to give a sound stimulus and at the same time closes (or breaks) the electric circuit. But for greater convenience, and to insure uniformity of stimulus, the sound hammer (fig. 36) is

preferable. In this instrument a steel hammer, H, strikes against a steel foot, F, being drawn to the latter by means of an electro-magnet against the resistance of a spiral spring, S.

For visual reactions various forms of apparatus exist, involving

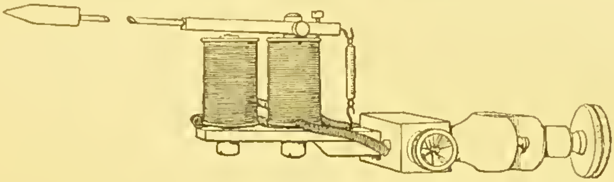

Fig. 37.

movement of a shutter or a pendulum, and so designed that a current is made or broken at the moment of exhibition of the stimulus. It is essential that the visual stimulus should be presented silently, and in muscular reactions that the stimulus be exposed immediately the screen begins to move. Otherwise the subject is apt to react to a noise or to the initial movement of the screen, instead of to the desired visual stimulus.

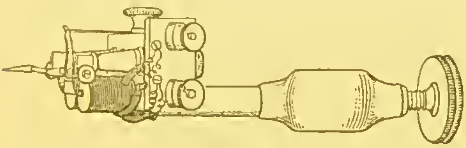

Fig. 38.

Reaction times may be recorded by the graphic method; a time signal (fig. 37) and a time marker (fig. 38) being brought to bear, one above the other, upon a travelling smoked surface. The time signal is arranged in the same electric circuit with the two pieces of apparatus above described, which present the stimulus and receive the reagent's response, respectively. The time marker records the vibrations of an electrically driven tuning-fork, vibrating, say, 50 or 100 times per second. By this means a tracing like the following may be obtained:—

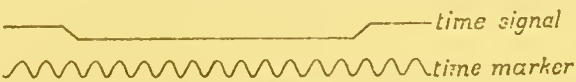

Fig. 39.

Hipp's chronoscope,[1] however, is a far more convenient instrument for recording reaction times (figs. 40, 41, 42). The clockwork of

[1] This instrument is undoubtedly of English origin, having been first made in 1840 by Wheatstone. A specimen was seen by Hipp at Karlsruhe in 1842, who subsequently constructed the model which goes by his name.

the chronoscope is started by pulling on one of the two hanging cords, S′ S″ (fig. 40), and it is stopped by pulling on the other cord. It is driven by a weight, W, which is raised by a key fitting into the centre of the lower dial. The crown wheels, C′ and C″ (fig. 41), which lie near the front of the clock, have 100 teeth. The balance wheel, E, lying above and behind the crown wheels, is regulated by a small tongue of steel, T, which is thrown into movement by the starting of the clock, and is accurately tuned to vibrate 1000 times per second. This steel tongue thus allows a single tooth of the balance wheel to escape every thousandth part of a second. The two dials, D′ D″, are divided into hundredth parts. The hand of the upper dial revolves therefore ten times every second, and each division of the dial corresponds to a thousandth part of a second, *i.e.* to 1σ. The hand of the lower dial is geared so as to revolve once every 10 seconds, each division of this dial corresponding to one-tenth of a second, *i.e.* to 100σ.

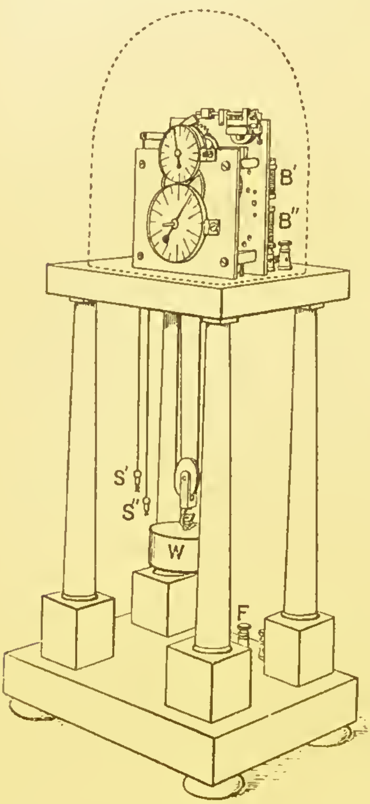

Fig. 40.

While the clockwork of the chronoscope continues in action, the hands of the dials may be arrested or started at any moment by means of the electro-magnetic mechanism at the rear of the instrument. For this purpose, either the upper or the lower pair of bobbins, B′ B″ (in rare cases both pairs) may be used at will; the lower or upper spiral springs, S′ S″ (fig. 42), being made appropriately tense by adjustment of the controlling levers, H′ H″, which are placed at the sides of the instrument. By this arrangement, after the current has ceased to flow through those bobbins which are being used, the armature, A, is immediately released from contact with the bobbins.

The movement of the armature, thus brought about by one or other pair of bobbins, serves to vary the play of the vertical rod, L, connected with the armature, A, upon the upper axis or spindle, *p p*, which passes horizontally from the upper dial through the hollow

axis of the crown wheels, C′ and C″, to the back of the instrument. When the armature is pulled down (by the action of the lower springs or magnets), the spindle, $p\,p$, and the hand of the upper dial are drawn back, so that a small cross-bar, J J, fixed on the spindle, fits into one of the teeth of the hinder crown wheel, C″, through which the spindle passes. The movements of this crown wheel are thus communicated to the spindle and to the hands of the dials.

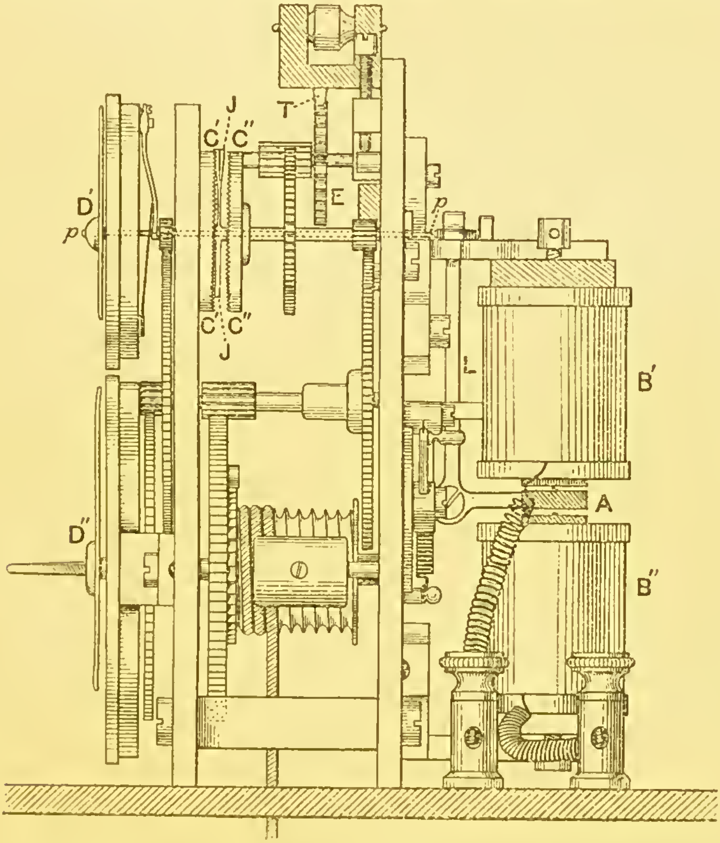

Fig. 41.

When, on the other hand, as in fig. 41, the armature is held up (by the action of the upper springs or magnets), the cross bar, J J, of the upper spindle no longer remains in the teeth of the crown wheel, C″; the spindle and the hands are seen to come forward, so that the cross-bar of the former now engages in the other crown wheel, C′, placed slightly nearer the front of the clock, which only differs from the former in that it is fixed instead of being movable.

Thus, in the former position of the spindle the hands move, while in the latter they are thrown out of action, although the clock-work is continuously in movement; and as these two positions are determined by the closure or interruption of an electric current, we are enabled, by putting the terminals, F, of the chronoscope in the same circuit with the rest of the reacting apparatus, to record the length of time in which the dial hands have revolved between the exhibition of the stimulus and the response of the reagent. Thus if A be (fig. 43) the sound hammer, B the battery or other source of current, C the subject's key, and D be one of the two pairs of terminals of the chronoscope; then, when the key is depressed, the circuit will be closed when the stimulus is exhibited (*i.e.* when the sound hammer falls), and will be broken when the subject reacts. With this arrangement, those two terminals of the chronoscope must be chosen which allow of magnetisation of the lower pair of bobbins. If now the clockwork of the chronoscope be started, movement of the clock hands is effected by making, and is arrested

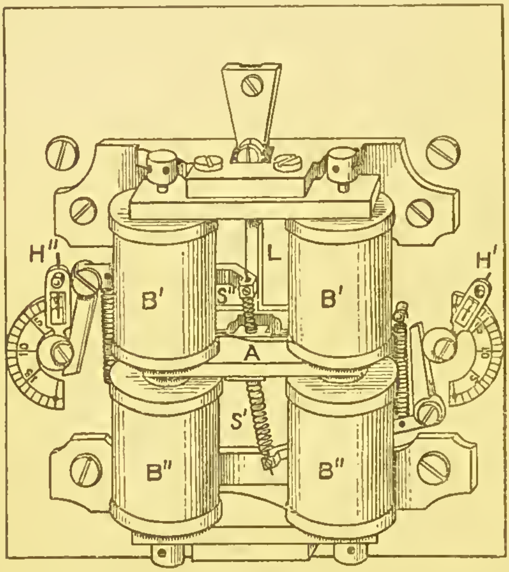

Fig. 42.

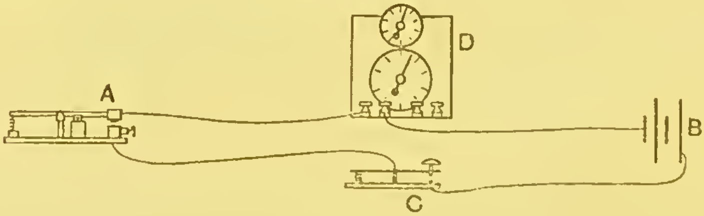

Fig. 43.

by breaking, the circuit. Supposing that, before such a reaction experiment, the hands of the lower and upper dials be at 35 and 80 respectively, the experimenter records their position as 3580. If after the reaction they occupy the respective positions of 37 and

42, he subtracts 3580 from 3742, and obtains the reaction time 162 in terms of σ.

[This is the simplest arrangement of the chronoscope; in which the act of exhibiting the stimulus and the response of the subject respectively make and break the chronoscope current. It is, however, sometimes desirable that the act of exhibiting the stimulus should break the chronoscope current instead of making the current, in which case the upper instead of the lower bobbins of the chronoscope must be employed; so that when the current is broken the hands of the dials are instantly put into action, and when it is re-made by the subject they are again put out of action. In this case the subject reacts by closing the current. But for accurate work it is undesirable that the response of the subject should consist in making a contact (a slightly variable error being necessarily introduced by such procedure). This may be avoided if the battery current, B (fig. 44), be given the choice of passing through (i.) a circuit of raised resistance containing the upper bobbins of the chronoscope, D, or through (ii.) an alternate circuit of lower resistance in which are placed the exhibiting apparatus, A, and the reacting apparatus, C. The resistance in (i.) is raised by the use of a rheocord, E. In this arrangement the current flows through the higher resistance circuit, *i.e.* through the chronoscope, until the stimulus is exhibited; whereupon the lower resistance circuit is completed and the current in the chronoscope circuit is so far reduced that the magnets of the chronoscope no longer restrain the hands from moving. As soon as the subject reacts, the lower resistance circuit is again broken, so that the current must needs confine itself to the chronoscope circuit and thus arrests the movement of the hands.]

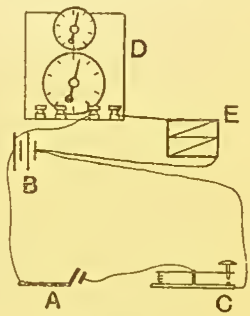

FIG. 44.

The chronoscope requires careful treatment in order to ensure uniformity and accuracy of readings. A commutator must *always* be introduced into the chronoscope circuit, so that the direction of the current may be reversed after each individual reaction, thereby preventing permanent magnetisation of the soft iron core within the bobbins. The intensity of the current should be of a known and constant value. For this purpose a rheocord and a galvanometer (or ammeter) are employed. The springs of the chronoscope must be safeguarded from fatigue.

The reliability of the chronoscope must be tested by some form of control instrument. One of the best-known forms, the control

hammer (fig. 45), essentially consists of a hammer, H, which during its fall successively makes and breaks (or breaks and re-makes), at L′, L″, a current flowing through the chronoscope. The actual time occupied in the fall of the hammer may be afterwards determined by attaching a piece of smoked paper to the hammer and by recording on it the vibrations of a stationary tuning-fork. The control time may be altered by varying the position of the weighted counterpoise or by lowering or raising the electro-magnet, B, through which an independent current passes, holding up the hammer until the time has come for its release.

[So long as alternate circuits (as shown, for example, in fig. 44) are not employed in the reaction current, the error of the chronoscope,

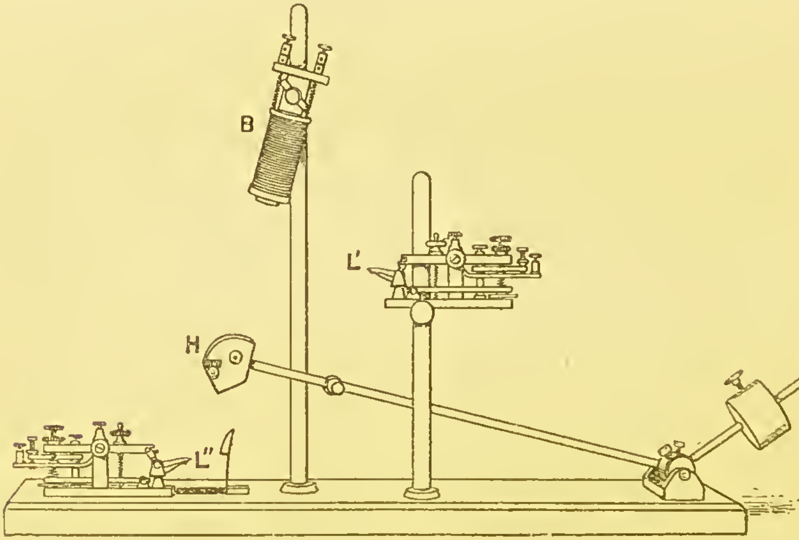

Fig. 45.

as tested by the control instrument, is usually the same for longer as for shorter intervals of time. When the error is proportionate to the length of the interval, we may suspect that the clockwork runs faultily, the error lying perhaps in the teeth or in the escapement.

Assuming, however, that the clockwork of the laboratory instrument is not at fault, we turn our attention to another source of error. A latent period of time necessarily elapses between the closure of the current and the attraction of the armature. Another latent period elapses between the breaking of the current and the release of the armature. It is desirable that these two intervals should be equal. They are each due, in part, to mechanical inertia, to which is added the gradual growth of magnetism in the case of the former,

and remanent magnetism in the case of the latter period. That is to say, magnetisation does not at once reach its full height, nor does it abruptly cease.

These two intervals may, in certain cases, be of considerable length, relatively to the time of running of the clockwork. They are affected by changing either the tension of the springs or the intensity of the current. It is found convenient in practice to vary only the current intensity.

Let us suppose that the hands are running when the chronoscope current is closed. According as the time recorded by the chronoscope exceeds or falls short of the value of the true control time, the flow of current should be diminished or increased by increasing or decreasing the resistance of a rheocord placed in the chronoscope circuit. The mean variation of the error may be often reduced by regulating the tension of the springs against which the armature of the chronoscope works.]

The chronoscope should be controlled before, and at the end of, every series, and in the middle of a prolonged series of reactions. The mean variation of a series of control tests should not exceed one hundredth of the mean of the recorded times. After each individual test the commutator must be regularly reversed, so that the current is passed in either direction through the chronoscope.

Erroneous readings are apt from time to time to arise from improper vibration of the steel tongue, T, which controls the balance wheel, E, of the chronoscope. Sometimes it vibrates with half its proper frequency, sometimes it shows other forms of irregularity. After a little experience, however, the proper pitch of the tone, which the tongue should emit before a control time or reaction time is taken, is easily recognised.

Care must be taken to interpret the position of the more slowly moving index of the chronoscope dials in the light of information yielded by the other index. Supposing, for example, that the former points exactly to 35 and that the latter points to 98, the reading must be taken as 3498, not as 3598. Were the latter the real reading, the index would point nearly to 36, instead of pointing to 35.

The experimenter and the subject are now in a position to take a series of ten control times with the control hammer,—using the upper or the lower electro-magnets of the chronoscope, whichever are required for the ensuing reaction experiments. When the results are satisfactory, they should proceed with the following experiment.

Simple Reactions.

Exp. 89. The subject should, if possible, be seated in a quiet room, remote from that in which the chronoscope is placed. An assistant should be with him, in order to record observations of the latter's behaviour during reaction (*e.g.* premature reactions) and to take down from him any introspective notes. The room in which the subject sits contains the apparatus exhibiting the stimulus, the key by which he responds to it, and an electric signal of some kind whereby the experimenter is able to warn the subject to prepare himself for the reaction. When this signal sounds, the subject gets ready, and if a finger (or Morse) key is used, he places his finger lightly on it, with his hand and arm comfortably supported.

The experimenter gives the warning signal, when his apparatus is ready and when the clockwork of the chronoscope has been satisfactorily started. After a nearly constant interval, preferably between one and two seconds, the stimulus is presented, either by electric means from the experimenter's room, or by the assistant who is in the subject's room. If the assistant presents the stimulus, care must be taken that the subject cannot see or hear any preparation for movement on the part of the former. In auditory reactions, the source of sound should be invisible to the subject. A dozen preliminary trials should always precede the records obtained from a hitherto unpractised subject.

The experimenter takes care that the current running through the chronoscope remains of uniform strength, as dictated by the previous experiment with the control hammer. He is careful to avoid any permanent magnetisation of the electro-magnets, by reversing the commutator after each reaction, and by only allowing the current to flow through the chronoscope when absolutely necessary. Before the first and every subsequent reaction, he takes down the times registered on the dials of the instrument. At the close of the series of reactions he subtracts successive values from one another, finds the average, the mean variation, and such other constants as are needful. If on different days a sufficient number of reactions can be obtained, a curve (or rather a polygon) may be prepared showing the distribution of individual reactions.

In natural reactions the subject receives no instructions; in sensorial reaction he is told to think only of the expected stimulus, and not to attend to the movement until he has received the stimulus; in muscular reactions he is told to concentrate his attention on the movement with which he is about to respond, and not to think of the expected stimulus.

A series of at least ten (preferably thirty or forty) reaetions should be obtained for each mode of reaetion. They must be preeeded by preliminary praetiee ; and they should be followed by some further reaetions, in whieh the subjeet attempts to reeord his mental behaviour by introspeetion. The diffieulties of introspeetion may perhaps be lightened if the subjeet limits himself to describing in some reactions his experienees anterior to the reception of the stimulus, in others his experienees upon its reception, and in others his experiences during and after the motor response to the stimulus. (Sueh "fraetionisation," however, is fraught with serious dangers.) He should speeially attend to the nature of his imagery and to the part played by volition in the various forms of reaetion.

Composite Reactions.

Exp. 90. Reaetions involving recognition are merely a more eomplete form of sensory reactions.

Reaetions involving diserimination may be most easily performed by exhibiting to the subject one or other of a number of known colours and instructing him not to reaet until he has elearly diserimi-nated the presented stimulus from the other possible stimuli.

Reaetion times involving ehoiee may be performed by furnishing the subject with two reaction keys, one for a finger of either hand. He is told that either a red or a blue stimulus will be exhibited, and that he is to reaet, say, with the right hand to red, and with the left hand to blue. In this ease an assistant exhibits the stimuli, always taking care that they follow in quite irregular order, and reeording the nature of the stimulus and the mode and details of the subjcet's response. The subject should introspeetively determine his ehange in attitude with inereasing praetiee.

Associative Reactions.

Exp. 91. The times of these reaetions are so long that they may be roughly studied, in default of speeially adapted experiments, by the assistant pressing down a Morse key at the moment when he exhibits or utters the stimulus word, while the subject lifts his own key and simultaneously responds with the associated word. Aecurate results, however, require an apparatus, enabling a word to be exposed, and causing the chronoseope current to be made (or broken) at the moment of exposure, together with a voice key or lip key for the subjeet, whereby the eurrent is broken (or remade). A series of free, or partly or wholly constrained, association reactions may be taken in irregular order, and the average times of the three groups ealculated,

EXERCISES ON CHAPTERS XII. AND XIII

Memory

The Memory Image.

Exp. 92. It is assumed that the subject has already familiarised himself with the general nature of memory images, by attempting to revive recent or familiar scenes or actions. He now rests his eye on a uniform black screen. After a minute the experimenter, opening a window in the screen (or by other means), suddenly exposes for about ten seconds a light or dark grey disc upon a background of medium greyness. When this exposure is ended, and the window has been closed, the subject continues dreamily to rest his eyes on the black screen, and he notes whether there is a single or repeated spontaneous revival (perseverance) of the memory after-image, whether the image can be reproduced volitionally, or whether no visual image, worthy of the name, is representable. Some little practice is often necessary for the subject to obtain good results. His success will be more assured if the screen be provided with blackened side wings, so that no external objects distract his gaze. Care must be taken not to confuse the sensory with the memory after-image (page 148).

The experiment may be modified by similarly exposing a second grey disc, somewhat lighter or darker than the first, the two exposures being separated by an interval of half a minute. The subject endeavours, when the second exposure is over, to compare the two greys, observing to what extent he makes use of the memory image of each.

Exp. 93. In a quiet, preferably darkened, room the subject listens for about twenty seconds to a tone uniformly and continuously sounding from some form of whistle. After the tone has ceased, he observes the memory image.

The subject should notice in these experiments that the memory image only appears and can only be held fast for a brief time. Its characters should be compared with those of the original presentation. He should observe the feeling of tension in the head and any changes in the localisation of this feeling, during the exposure of the disc and during the appearance of the memory image. The effects of momentary and prolonged exposures should be compared.

The Classification of Associations.

Exp. 94. The experimenter prepares a list of thirty words, choosing them so that all kinds of imagery (visual, motor, etc.), are represented. By the aid of convenient apparatus, they are successively exhibited to the subject, who takes care each time to express the first idea that occurs to him. The association times and the words returned are noted by an assistant.

The experimenter classifies the associations according to the scheme on page 152, obtaining all possible help from introspective analysis by inquiry after every answer. He then observes whether any light is thrown, by introspection and by the speed and nature of the replies, on a predominant type of imagery, or on other individual peculiarities.

If time permits, the experiments described on pages 145–146, and the serial method mentioned on page 151, may be performed. The special point of interest in these experiments is the great individual differences they disclose.

Methods of Measuring Memory.[1]

The Saving Method.

Exp. 95. Each member of the class prepares a series of twelve senseless three-letter syllables, taking care—

(*a*) that two consecutive syllables do not form a sensible word ;

(*b*) that the same vowel is not repeated in two consecutive syllables ;

(*c*) that no two letters of one syllable recur in another syllable of the same series ;

(*d*) that the final letter of one syllable is not the initial letter of the next.

These syllables are to be written out in large printed characters, one beneath the other, each series on a separate sheet of paper, which is then handed by the writer to his neighbour. At a given signal each person begins silently to learn the series by the learning method. A noiselessly swinging pendulum (or a metronome) ensures a constant rate of reading. At the first correct reproduction the experiment is stopped. The repetitions are counted at the close of the experiment by observing the number of discs of cardboard, one of which is dropped from the hand of the subject after each repetition. After a given

[1] An elementary class cannot be expected to give sufficient time to experiment and to preliminary practice, in order to obtain quantitative results of any value. They should, however, familiarise themselves with the experimental methods.

interval, say one hour, the series is relearnt as before, and the saving in repetitions is noted.

The Scoring Method.

Exp. 96. The following is Müller's arrangement of apparatus for this method. The student should familiarise himself with the use of such instruments as the laboratory possesses which are available for the purpose, should the laboratory not possess the apparatus which is here described.

In this method the syllables are written on a cylinder, and during the rotation of the cylinder on its horizontal axis they are successively exposed to the subject before a small window in a screen. During reading, the subject gives so far as possible equal attention to each syllable, and accents them as directed. In the interval between the last reading and the re-exhibition, he is careful to avoid thinking over his lesson.

The re-exhibition apparatus consists of a polyhedral prism, rotating on a horizontal axis, on each side of which is printed the first syllable of some pair belonging to the series of syllables already learnt. This prism is concealed from the subject's eye by a releasable screen, which falls when the subject breaks an electric circuit, thereby exposing a single syllable printed on the presented side of the prism. By closing another electric circuit, the falling screen sets a Hipp's chronoscope in action at the moment of exposure of the syllable. The subject, in giving out his reply, stops the movement of the chronoscope owing to its electrical connection with a lip key or a voice key which moves when he speaks. The chronoscope readings, thus obtained for the various pairs of syllables, are indeed not identical with, but they may be taken as a measure of, the time occupied in reviving the associated syllable.

Economical Methods of Learning.

Exp. 97. The experimenter writes in a clear hand a dozen verses of poetry on the blackboard. The subjects note the number of silent repetitions necessary to learn them by the entire method, counting the repetitions, as in Exp. 95, by dropping, as before, a small disc of cardboard from the hand at each repetition. After five minutes' rest, the number of necessary repetitions is determined in order to learn a further series of equally difficult verses by the sectional method, the series being learnt in two equal sections. After similar intervals, a third series is learnt by the entire method, a fourth series by the sectional method, in which the series is divided into three (four, or six) sections, and a fifth series by the entire method.

The class should compare the economy in repetitions for these three methods, and make careful introspective records of their experiences. They should consider what further factors need to be investigated, in order to determine more accurately the relative economy of methods of learning.

EXERCISES ON CHAPTER XIV

Muscular Work

Muscular Fatigue.

Exp. 98. The dynamometer and the ergograph are the two instruments which have been used in the psychological study of muscular fatigue. Observations have been confined to local, they have not extended to general, bodily fatigue.

The dynamometer registers the squeeze or pull of the hand or finger against a steel spring. It may be used in two ways : either to record the maximal force of a momentary muscular contraction under varying conditions, or to record the variations in that force when prolonged effort is made to maintain a state of maximal contraction. The instrument, however, has various drawbacks. In the first place, the maximal force varies with the suddenness with which the contraction is made. Secondly, the pressure of the bar or handle against the skin is apt to be very painful, and therefore to inhibit the full force of the contraction. Thirdly, the movement required is so complex that there is no security against bringing into use different muscles, or against contracting different muscles to varying extents, at different times in the course of the investigation. A modified form of the dynamometer is employed and figured in exp. 155.

The ergograph (fig. 46) is especially adapted for the study of simple movements in which very few muscles are involved. The most usually studied movement consists in extending and flexing the middle finger. It is the essence of a good instrument that, by the rigid fixation of the arm, hand, and other fingers, all auxiliary movements be, so far as possible, excluded, and that a minimum of discomfort attend the recording of the ergogram. In most instruments the work is done (that is to say, the weight is lifted) with the hand placed palm upwards ; in others (cf. fig. 46) the hand rests with the palm downwards.

In Kräpelin's ergograph (fig. 46) the arm is placed on a firmly fixed platform F, and is clamped by the cross-bars A and B. The

middle finger lies midway between the first and third fingers, which are separated from it by the right-angled plates C and D. It is

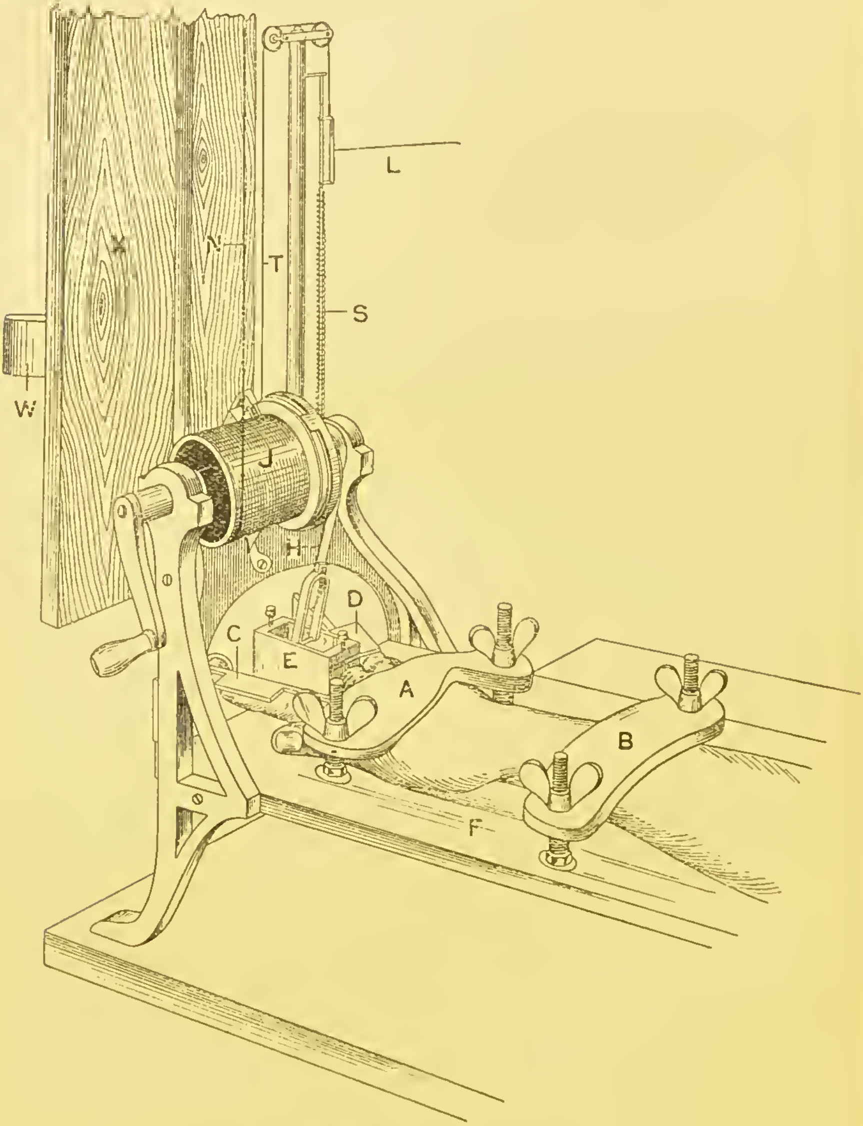

FIG. 46.—Kräpelin's Ergograph.

comfortably but firmly secured by means of screws within the box E, and is free to execute up- and downward movements. The several parts which thus fix the fingers are movable and are graduated, so

that the hand can be repeatedly replaced in the same position. The movements of the middle finger are communicated by the steel ribbon H to the axis of J, and thence by the cord T to the lever L, which is raised against the action of the spring S. L records the finger movements on a travelling smoked surface. The upright board X is 10 feet or more in height. At its top it bears a pulley, round which passes a long wire, attached at one end N to the spirally grooved surface J, and at the other end to the (variable) weight W placed on the other side of the board.

Flexion of the middle finger rotates J, and thus raises W, but the axis of J is so arranged that no reverse movement of J or lowering of W occurs during relaxation of the finger. In virtue of this contrivance, it is easy to calculate the total height to which W has been raised during any experiment, by means of a vertical scale placed on the rear surface of X.

In a series of preliminary experiments, the weight which has to be raised must be regulated according to the physique of the subject and according to the prescribed frequency of movement.

To obtain an ergogram of the usual form, as shown in fig. 4, the weight must be relatively heavy. A metronome is used to mark the rate of rhythm. The subject's eyes are screened from the smoked surface, on which the height and number of his contractions are recorded. When the height and number of the contractions, or the total height through which the weight has been lifted in a known time, are known, the amount of work can readily be expressed in units of work (kilogram-metres).

Muscular Practice.

Exp. 99. It is not difficult to devise experiments which shall test the degree of practice in speed and accuracy of movement. Learning how to typewrite, or aiming successive balls at the centre of a target, are examples. The target may be covered with two sheets of paper, between which is inserted a piece of carbon paper. By such means the effects of increasing practice, fatigue, and the extent of retention of practice can be quantitatively determined.

Mental Work.

Methods of Testing.

Exp. 100. A method of determining the spatial threshold is described in exp. 103.

The chief difficulty of the "combination," "letter-erasing" and

"learning" tests lies in evaluating the results. The errors may be either of commission or of omission, and it is not easy to apportion the "bad marks" which each kind of error should deserve. Some investigators allow only half a bad mark to an error of transposition in the learning test; others graduate the mark according to the extent of transposition.

In the combination test, it is essential that the material should be of constant interest and difficulty for different subjects, and for the same subject at different times. An approach to uniformity may be attained by confining the omitted words to some definite part of speech, *e.g.* to verbs.

In the letter-erasing tests, the material should again be of constant interest and familiarity. This ideal is best reached in the case of adults by using nonsense words, or in the case of children by using a foreign language which is known to be absolutely meaningless to them. If pages of nonsense words are specially prepared, it is well to arrange the words so that every half page contains a constant number of examples of the letter which the subject is enjoined to erase.

The methods employed in the learning test have been already discussed on pages 153–156.

For the simple addition of the calculation tests, special books of figures (*Rechenhefte*) have been prepared under Kräpelin's direction. The subject adds each figure to the next and writes down the result. He then starts afresh and adds the next pair of figures, and so on. He makes a mark at the figure reached whenever the time signal is sounded.

These books are not so suitable for multiplication, as special arrangements are necessary so that the various pairs of figures multiplied shall be of fairly uniform difficulty.

Satisfactory experimental results can hardly be expected from students whose opportunities for investigation are confined to the hours of class laboratory work. In a few initial experiments it is impossible to eliminate the enormous influence of accommodation and practice. Nevertheless, the student cannot be too strongly urged to familiarise himself with some, at least, of the methods described in the text, and to preserve a record of his introspections made after submitting himself to the tests.

EXERCISES ON CHAPTER XV

Psycho-physical Methods

Method of Mean Error.

Exp. 101. The experimenter should apply this method to an investigation of the conditions affecting the accuracy with which the subject can make one line equal to another. An inexpensive form of apparatus for class work is one in which two white threads are displayed upon a black screen, the length of either being adjustable by an arrangement which the subject can easily manipulate behind the screen. A series of ten observations should be taken under each of the following conditions : the standard lying (*a*) to the right of, (*b*) to the left of, the variable ; and a further series should be taken to show any differences dependent on whether the subject has to shorten or lengthen the variable line in order to make it equal to the standard. The apparatus should be held so that the plane of the screen cuts the line of vision at right angles ; that is to say, it should be held vertically in front of, or horizontally immediately below, the eyes.

A few preliminary practice experiments should precede the actual record of results. Every group of ten observations should be divided into two sub-groups, each of five observations, and the order of taking the various sub-groups should be so arranged that the influences of practice and fatigue may be nearly constant for each group. Within the limited time available in class work, the complete equalisation of conditions is, of course, impossible.

The experimenter determines the constant and average error and the mean variable error (*a*) from the whole of the results obtained, and also from the results obtained when the variable lies (*b*) to the left and (*c*) to the right of the standard line. He may thence deduce the space error. He should also determine the constant error according as the variable has been (*d*) shortened or (*e*) lengthened by the subject.

Examples of the application of the Limiting Method are given in exp. 102, of the Constant Method in exp. 121, and of the Serial Method in exp. 103, and elsewhere.

EXERCISES ON CHAPTER XVI

Weight

THE SIZE-WEIGHT ILLUSION.

Exp. 102. The experimenter employs the series of canisters (fig. 47) provided in the laboratory, one of them being half the breadth or half the height of the others. This, loaded with shot so as to weigh, say, 200 grams, serves as the standard, while the larger canisters, differently weighted, serve as the variables. A metronome or silently swinging pendulum may be used to mark the rate with which the subject must raise and lower each canister, and to preserve a constant interval between handling each member of the various pairs of canisters. A horizontal cord should be stretched, say, six inches, above the height of the canister so as to ensure a constant height of lift. The series of canisters is screened by the experimenter from the subject's view. The experimenter successively places the canisters so that the subject lifts each canister from the same spot, sometimes the constant, sometimes the variable, is lifted first. In this way the space and time errors (pages 203, 266) are avoidable. The subject grasps each canister by the body, not by the handle.

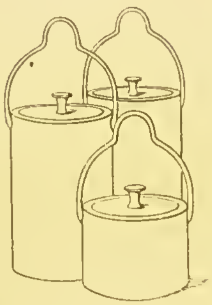

FIG. 47.—The small canister is employed with the larger ones in measuring the "size-weight" illusion. Only two of the larger canisters are here figured; in actual experiment a considerably larger number is necessary. The larger canisters are to external appearance exactly similar, but they are differently weighted with shot, the lids being removable. The canisters are *usually* lifted by one finger, which is inserted beneath the handle.

The experimenter first plans a brief series of pairs of lifts by the limiting method n order roughly to determine the variable weight which appears to the subject equal to the standard. In these preliminary experiments the variables should range between 280 and 400 grams, and differ by increments of 20 grams.

Then a series of experiments is conducted either by the method of serial groups or by the constant method. The beginner should choose the former, which has already been sufficiently described on page 209, and is further exemplified in exp. 103.

[The more advanced student may adopt the constant method. Here the variable canisters differ by increments of 10 grams, and the value of the central variable is that which (as determined in the preliminary experiment) appears approximately equal to the smaller canister, *i.e.* the constant. Five variables should be used, and each should be presented in irregular order, say eight times, with the constant.

The subject's answers, "heavier," "equal," "doubtful," or "lighter," should uniformly refer to the second canister lifted. The experimenter divides the "equal" and "doubtful" answers equally between the "heavier" and "lighter" answers (page 214). He then determines (by one of the methods alluded to on page 215) the value of the canister which may be expected to give equal numbers of "heavier" and "lighter" answers. This is evidently the weight of the variable which appears to be equal to that of the constant. We have thus measured the size-weight illusion.]

EXERCISES ON CHAPTER XVII

Local Signature

The Spatial Threshold.

Exp. 103. The subject rests his arm comfortably on the table, extensor surface downwards. The experimenter marks in ink a point on the subject's forearm, which is to indicate the middle of the region to be investigated. Having found a distance which is just sufficient to be decidedly above the subject's spatial threshold, the experimenter applies the compass points, thus separated, to the subject's arm for about two seconds. The latter, having his eyes closed, decides whether he is being touched by two points or by one. The compass should be applied ten times with both points touching, and ten times with a single point touching the skin, in irregular order. Then the distance between the points is to be reduced by five millimetres, and another series of twenty stimulations is begun. The distance is in this way reduced, until two wrong answers in ten are obtained for the answers to double touches. This may be conventionally regarded as the threshold.

Care must be taken to apply the two points simultaneously, and with equal and constant pressure. When one point is used, it should be applied near one or other of the spots to which the two points are applied.

The subject should carefully note his experiences and take care that they are recorded. Sensations of cold should be avoided. The subject should, in particular, analyse his experiences near the threshold. A second series of experiments should be made, so that he may discover, so far as possible, the basis of his improvement with practice. A third series may be made, in which the subject is told each time by the experimenter whether his answer is correct or not. Here he should try to find the reasons for his wrong answers, and the experimenter should note the results of this modification of the experiment.

It is worth while to bear in mind the proposal which has been put forward by Binet, that subjects are divisible into three classes, according to their behaviour in this experiment. The *simplistes* only record a double touch as such, when two distinct tactile sensations are present. They show an abrupt transition from answers which are all correct, to answers many of which are wrong. They never err in describing a single touch as double. The *interpretateurs* make ample use of inference, and avail themselves of the difference between the effects produced by double stimulation and those produced by single stimulation, even when a double touch is not actually experienced (page 232). Their threshold is less definite. The *distraits* are those who, owing to their liability to distraction, are apt to confuse the difference between single and double touches, and thus sometimes describe single as double touches. This latter illusion, however, is certainly not always due merely to lack of attention; its causation requires future investigation.

Exp. 104. The experimenter takes the compass, the points of which are set at a distance 2 cm. apart, and draws it with uniform movement and pressure across the cheek of the subject from ear to lip. The subject observes the changes in apparent distance between the points and in their apparent rate of movement.

Aristotle's Experiment.

Exp. 105. The subject places his hand palm upwards on the table, and the experimenter crosses the subject's ring finger over the middle finger. The experiment consists in simultaneously touching the adjacent sides of the tips of the crossed fingers with a single object. This is done by the experimenter, the subject being blindfold and ignorant whether he will be touched by one or by two objects.

Several modifications of the experiment have been described. Instead of touching the ulnar side of the middle and the radial side

of the ring finger, as above, two touches may be simultaneously applied, one to the radial side of the middle finger, the other to the ulnar side of the ring finger. Or the distances may be compared when two compass points are simultaneously applied one to each of the crossed fingers, the points first being close together, and secondly much wider apart. Or, again, the compass points may be applied diagonally (instead of, as in the previous experiment, transversely) across the two finger-tips, and the subject be asked in which direction the diagonal lies. Greater pressure may be made on one of the two points, the subject being asked to state which finger is being pressed upon.

The results differ for different individuals, some of the illusions being present in certain people which are not obtainable in others.

Another striking variation of the experiment is as follows. Holding the compass points so that the line joining them is vertical, the experimenter applies them, one to the upper, one to the lower lip of the subject—(i.) when the lips are in the normal position, (ii.) when they are laterally displaced from each other. The subject estimates the inclination of the imaginary line between the compass points.

Absolute Localisation.

Exp. 106. The experimenter makes a "life size" outline sketch of the flexor surface of the subject's left forearm, as it rests comfortably upon a table. He draws in such veins and tendons as may serve as landmarks. The subject is blindfolded. His right hand hangs by his side, holding a blunt-pointed wooden rod. After a warning signal, the experimenter touches the subject's left forearm with a similar rod. He removes it after two seconds, whereupon the subject, still blindfold, brings his own rod as precisely as possible to the same spot. The experimenter carefully measures the distance between the two touches, and records the position of each in the diagram, joining the two by a line which bears an arrow indicating the direction of the error, while the length of the line indicates the extent of the error of localisation.

Several such tests are made on various parts of the subject's forearm, the experimenter taking care that the conditions (*e.g.* the duration of his touch, the amount of pressure exerted by it, and the interval between the two touches) remain as constant as possible. The order of the successive tests should be noted on the diagram, and at the end of the series the records should be investigated with the object of showing any general tendency of error, and the influence of practice and of the position of the touch. The experimenter must

always be on the look-out for anything in the behaviour of the subject which may throw light on the attitude of the subject during localisation. The latter makes careful introspective observations throughout the experiment, with the same object of revealing the psychological factors involved in his acts of localisation.

The influence of a comparison of the two touches by the subject may be eliminated by forbidding him to move his rod after he has once touched his skin. The influence of visual imagery may be heightened by requiring the subject to open his eyes and apply his rod to a plaster cast or to a photograph of his arm, instead of to his own arm, or by asking him in one series of the previous experiments to attend solely to his tactual experience, and in another series solely to his visual imagery. Visual imagery may be entirely dissociated from tactual experience, if a previously marked spot on his arm be shown to the subject, who thereupon closes his eyes and endeavours to touch it. Or the combined influence of vision and touch may be further investigated, by allowing the subject to see the experimenter's touch before he closes his eyes and attempts to localise it.

The influence of visual factors on tactual localisation is so great as to increase the accuracy of the act considerably. It is often shown in the tendency of the subject to displace the touch towards serviceable visual landmarks, *e.g.* bony prominences, the margins of the arm, the flexion folds of the skin.

The Visual Perception of Movement.

Exp. 107. The subject makes a series of vertical marks along the smoked surface of a drum rotating on a vertical axis. He observes these marks for fifteen seconds during rotation. He then stops the drum and continues to fixate one of the marks on the smoked surface, observing the after-effects of movement.

Exp. 108. The subject fixates a horizontally striped black and white background, a central vertical strip of which can be set in continuous motion. He observes the apparent movement of the really fixed parts of the ground, which is set up during actual movement of the central strip, and the general reversal of movement occurring when the central strip is brought to rest.

Exp. 109. The subject observes the after-effects, obtained after rotating on the colour wheel a white disc, on which a broad black spiral figure has been traced. The after-effects should be noted—

(i.) when fixation is still confined to the now resting disc, and (ii.) when it is transferred to other objects.

The subject now conceals one-half of the rotating disc by a white screen, and fixates a point on its edge, so that part of the retina receives the moving image of the half-spiral, and the other part receives the image of the stationary, screen. He observes the after-effect when the rotation is stopped.

Exp. 110. The subject draws a straight line A B C D E (fig. 48) and divides it into imaginary quarters. He then draws a compass point slowly along the imaginary arc F B G D H. Fixing his regard

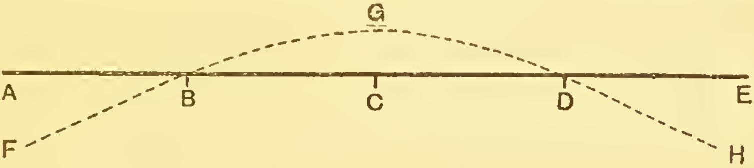

FIG. 48.

steadily on the moving point, he observes what apparent changes take place in the direction of the line A C as the point moves from F to G, and in the direction of the line C E as the point moves from G to H.

EXERCISES ON CHAPTER XVIII

Sensibility and Sensory Acuity

VISUAL ACUITY.

Exp. 111. The determination is best made out of doors on a dull cloudy day. For the E method either Snellen's illiterate test-types (fig. 49) or Cohn's arrangement (fig. 50) may be employed. The following applies to the use of the test types.

One eye of the subject is covered, while the other is tested. He stands at a distance of 15 metres from the letters. The experimenter points to the largest letters individually; the subject is asked to place in a corresponding position the E with which he is provided, or merely to state whether the open ends of the E face right, left, up or downwards. The experimenter proceeds from larger to smaller letters until he reaches a line in which two mistakes in ten replies occur. This is an arbitrary limit, but serves satisfactorily.

The subject is now moved a metre nearer to the letters, and the test is resumed. He advances in this way by successive metres until he can read the smallest type, known as No. 5, without making more than two mistakes in ten answers.

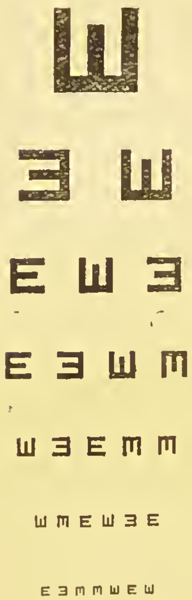

Fig. 49.

The visual acuity is expressed as a fraction, the numerator denoting the distance in metres at which the subject can just read a letter, the size of which is the denominator. The size of a letter is denoted by the number of metres' distance at which that letter should be read by persons possessing so-called "normal" acuity. For such persons the numerator and denominator have the same value.

The subject must make careful introspection of his mental procedure, and of any alterations occurring therein during the investigation.

If opportunity permit, he should compare the numerical and introspective data thus obtained with those obtained by the use of such other tests of visual acuity as the laboratory possesses.

Auditory Acuity.

Exp. 112. The determination is best made out of doors on a still, windless night. Politzer's acoumeter (fig. 51) serves as a convenient source of sound. The subject turns one ear towards this instrument, which is held between the experimenter's fingers, at a distance of five metres. The subject's other ear should be lightly stopped with cotton wool. The small percussion hammer of the acoumeter is allowed by the experimenter to fall five times at irregular intervals. He utters a warning "Now!" before the first fall, and the subject exclaims "Yes" or "No," as he hears or fails to hear the sound. The subject is forewarned that sometimes no sound will be given, and the experimenter takes care irregularly to interpose five such catch experiments among every five sounds.

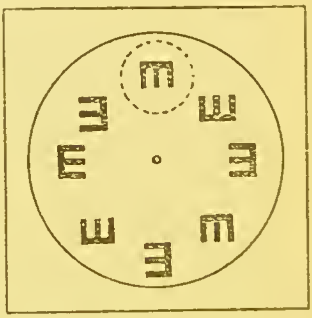

Fig. 50. — The letter E in various positions is drawn in black on a white card, as in the figure. This card is covered by a cardboard disc, in which a circular window is cut. By rotating the disc, the experimenter can exhibit to the subject any E he desires.

The experimenter increases his dis-

tance from the subject by a metre, and sounds the instrument five times, and gives five catch experiments as before. The experimenter is careful to record all the subject's answers. He continues to withdraw the instrument metre by metre in this way, until the subject fails to hear one of the five sounds. The experimenter then gives another series of five sounds and five "catches," at the same distance; and if another sound is missed, this distance may be arbitrarily regarded as the threshold.

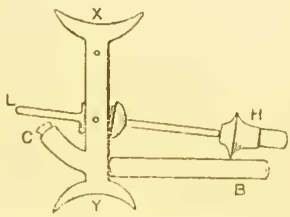

FIG. 51.—This instrument is held between the thumb and second finger at X and Y. The lever L is depressed by the forefinger until it touches the cork C, and then it is suddenly released. By this means the metal hammer H is allowed to fall freely from a constant height on to the bar B.

The experimenter, however, should increase his distance still farther several times, and observe the resulting replies. He should then gradually bring the instrument nearer to the subject by the same stages, and observe the distance at which not more than two sounds in ten are missed by the subject.

Throughout the experiment, the subject carefully observes his experiences, and at the close writes a full account of his introspection. The subject and experimenter then endeavour to correlate the results of introspection with the answers given, paying due regard to the illusions and irregularities in the subject's answers.

Olfactory Acuity.

Exp. 113. The experimenter dissolves a gram of camphor in 1000 c.c. of odourless distilled or rain water. He prepares from this a series of camphor solutions, of strengths 1 : 4000, 1 : 8000, 1 : 16,000, 1 : 32,000, etc. A number of cylindrical glass tubes, closed at one end, must be in readiness. They should measure about 75 mm. in height and 25 mm. in width, and be scrupulously clean and free from smell.

The experimenter first attempts to arrive at an extremely rough determination of the olfactory acuity of the subject, by asking him to smell the variously diluted camphor solutions successively. Only one or two minutes should be given to this part of the experiment, in order to avoid the onset of fatigue. The solutions are, therefore, rapidly sniffed in succession, until a solution is reached in which no odour of camphor can be detected.

The experimenter begins with a camphor solution which is a stage stronger than that which appears to be roughly liminal. While the

subject is resting (in order that he may recover as completely as possible from the just-mentioned procedure), the experimenter takes four of the cylindrical glass vessels, two of which are to contain 50 c.c. of odourless water, and two the same amount of the solution of camphor. The vessels are marked, preferably on their base, so that the contents of each are identifiable only by the experimenter. He now prepares a scheme of five different orders in which the four vessels are to be successively presented to the subject. It is well to prepare two such schemes, and to use sometimes one, and sometimes the other, so that the subject cannot possibly become acquainted with the orders.

An interval of fifteen minutes having elapsed, the four tubes are now set before the subject, who bends over and smells them successively. He is not allowed to touch them, or to return to a solution after he has given a reply. He is to answer "Camphor" or "Water," before he proceeds from one solution to smell the next. The subject then turns his back, while the experimenter changes the order of the same four vessels, in accordance with his scheme. The subject smells them again. The order is then changed, and they are smelled again, the procedure being repeated until the twenty replies are recorded. Record is carefully kept of all answers, and an arbitrary threshold is fixed which allows two wrong answers in ten in respect of the camphor solutions.

If, as is probable, the limit has not been reached, the experiments are continued by substituting a weaker solution of camphor in the next series.

A pause of ten minutes should be allowed in passing from one series of twenty answers to the next.

Occasionally a fifth vessel containing either camphor solution or water, or instead of four only three vessels, may be exposed, in order to avoid certain inferences on the part of the subject; but the cautions mentioned on page 209 must be borne in mind.

The experimenter should gradually pass to a solution the strength of which is definitely below that required for the arbitrary threshold. He should then reverse the previous procedure and present increasing strengths of the solution until the threshold is once again reached and overstepped.

Visual Adaptation.

Exp. 114. The effects of dark adaptation (exp. 69), and of adaptation to colourless and colour stimuli (exp. 74) have been already demonstrated. The student may investigate the effects of wearing coloured glasses for some time.

Purkinje's Images.

Exp. 115. The experimenter and the subject are in a dark room. The former concentrates the light of a candle by means of a double convex lens of short focus on to the outer (temporal) corner of the subject's sclerotic, who turns his eye inwards, regarding preferably a light-coloured patternless wall. The subject will soon see the shadows of the retinal vessels as a dark arborescence on a yellowish-red field. Under ordinary conditions these vessels are invisible, mainly owing to sensory adaptation.

The Blind Spot.

Exp. 116. The existence of the blind spot, the point of entrance of the optic nerve, may be conveniently demonstrated here, although the filling out of this spot (which occurs under the ordinary conditions of daily life) is not exactly an instance of adaptation. Although the spot is devoid of rods and cones, the subject irresistibly supplies the

Fig. 52.

sensations which are actually wanting there, being guided by the mode in which neighbouring sensitive regions of the retina are being simultaneously stimulated. A simple method of demonstrating the blind spot consists in closing one eye (the left) while the other is fixed on a point marked on a card (fig. 52). At some distance to one side of the point the card bears a circle, which disappears when the card is moved to such a distance from the eye that while the image of the point falls on the fovea, that of the circle falls on the blind spot.

Auditory Adaptation.

Exp. 117. The subject places the ends of a rubber tube one in each ear, and sits before a table on which the tube rests. The experimenter gently rests a vibrating tuning-fork on the midpoint of the tube, compressing the latter to one side so that the tone is conducted only to one ear. As soon as it ceases to be audible to the subject, the observer gently releases the tube on the other side of the fork, so that the hitherto unused path is now available.

Exp. 118. The subject places a vibrating fork on the vertex of his head and retains it until the tone appears to have died away. Then he removes it only for an instant and places it as before on the head.

If in these two experiments the tone is again heard after it had disappeared, the student should consider the various factors on which the phenomenon may depend.

EXERCISES ON CHAPTER XIX

Experiences of Identity and Difference

Weber's Law.

Exp. 119. The experimenter and subject should perform a series of experiments with weights, using the limiting method described on page 205.

The Least Perceptible Difference of Pitch.

Exp. 120. Probably tuning-forks will be the most convenient instruments for the student's use. No source of sound, however, is entirely free from disadvantages ; there is varying difficulty in securing uniformity of loudness, pitch and timbre. The method of serial groups (page 209) may be recommended for the elementary student.

The influence of time order (standard presented first or second) should be studied. Full introspective records should be obtained from the subject, with regard to imagery, tendencies to movement of the glottis, and his modes of arriving at a judgment.

The Absolute Impression.

Exp. 121. The experiment described on pages 268–272 should be performed in the laboratory. A standard weight, S, of 400 grams, and four variable weights, $S \pm d$, and $S \pm 2d$, may be used, d being 20 grams. The answers should be scheduled as follows :

Order	$S-2d$	$S-d$	$S+d$	$S+2d$
1				
2				
3				
4				

Here the percentage of correct judgments, when S is lifted with $S-2d$ and $S-d$, corresponds to the a judgments, and the percentage of correct judgments, when S is lifted with $S+d$ and $S+2d$, corresponds to the b judgments of the text. The four orders in the schedule refer

to the possible combinations of different temporal and spatial orders (e.g., a_1, a_2 ,a_3 ,a_4) mentioned in the text.

The variables should be used with the standard in quite haphazard order, until (say) each variable has been presented five times in each of the four orders, that is until 80 judgments have been recorded. "Doubtful" and "equal" judgments may be divided equally between the right and wrong judgments (page 214).

Eighty answers will provide material for the student to elucidate the influence of the absolute impression, the general tendency of judgment and the effects of time and space order. But no confidence can be placed in the results of so few observations.

Equal-Appearing Intervals of Brightness.

Exp. 122. Two "standard" grey papers, a and b, of different brightness are presented upon a black or white ground. Accompanying them is a third paper, the variable c, one of a series of various greys. By one of the recognised psycho-physical methods the experimenter has to find a paper c of such brightness that to the subject the difference between a and b appears equal to that between b and c. The papers must be of exactly the same size and uniformly illuminated. The light values of the various grey papers having been determined as described below, the relation of the intensities of the stimuli a, b, c to the sensation differences can be investigated. The chief causes of departure from Weber's law have been already sufficiently discussed in the text.

The light values of the grey papers may be determined in the following manner. It may be assumed that the greatest value of reflected light obtainable from the surface of a paper is afforded by a sheet of baryta-covered paper. This will serve as the standard, and will be given the value of 360. The light values of other white, grey, and black papers may be expressed in terms of the standard, a paper yielding half the light of the standard receiving the value 180, and so on. It may be further assumed that an absolutely black background is obtainable by looking into a long tube, say 75 cm. long and about 30 cm. in diameter, closed save for a small opening, and lined with black velvet. Before this opening a colour wheel is set up, and on the colour wheel is rotated a smaller disc of the paper to be tested and a projecting sector of larger radius, of the standard paper. This sector being rotated with sufficient speed before the black aperture, flicker is finally abolished, and an outer ring is obtained which is comparable with the smaller disc on the colour wheel. The arc of the sector is increased or diminished until the two colourless surfaces are identi-

cal. The light value of the paper to be tested is then given by the number of degrees covered by the arc. Of course, any white paper may be used as, and in place of, the standard, if it have previously been standardised with the latter.

The most convenient manner of arranging the papers on the colour wheel is here indicated (fig. 53). A represents the diameter of the smaller disc, the paper to be tested. B represents on the same scale the standard paper which is placed behind A on the colour wheel. The size of the projecting sector is so chosen that on rotation of the wheel the outer ring is darker than the inner disc. Behind B is placed a second piece of the standard paper B′ precisely similar to it. Then B and B′ can be accurately superimposed, or B′ can be turned round so that more of its segment comes to project beyond the segment of B, until upon rotation of the wheel the desired match is obtained.

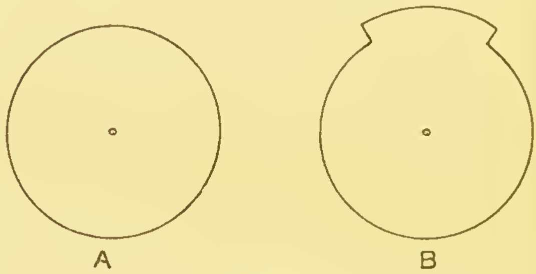

FIG. 53.

When once the light value of a second paper has been estimated, the value of any third paper may be readily found without the use of a dark chamber by rotating a disc of the latter paper on the colour wheel, while behind it are arranged two larger discs of the already standardised papers, slit from centre to periphery in the ordinary fashion, and movable one over the other, until on rotation the outer ring and inner disc match one another. If, for example, the match requires 125° of the standard paper and 235° of the already standardised grey paper, and if their light values be 360 and 75 respectively, then the light value of the paper in the inner ring is $125 + \frac{235 \times 75}{360} = 173{\cdot}96$ nearly.

EXERCISES ON CHAPTER XX

Binocular Experience

BINOCULAR COMBINATION.

Exp. 123. Two similar shillings are placed, about 15 cm. apart, on a glass plate which is held close to the mid-line of the body. The

image of a third single intermediate shilling can now be obtained by binocular combination, the eyes fixating a pencil point which is held (i.) nearer to or (ii.) farther from the eyes than the two coins. The glass plate should be moved towards or away from the fixation point until binocular combination is effected. Attention should be drawn to any differences in the ease of combination and in the size or localisation of the combined image, according as the coins lie nearer to or further from the eyes than the point of fixation.

Exp. 124. The student should familiarise himself with the theory and use of Wheatstone's mirror stereoscope and Brewster's prism

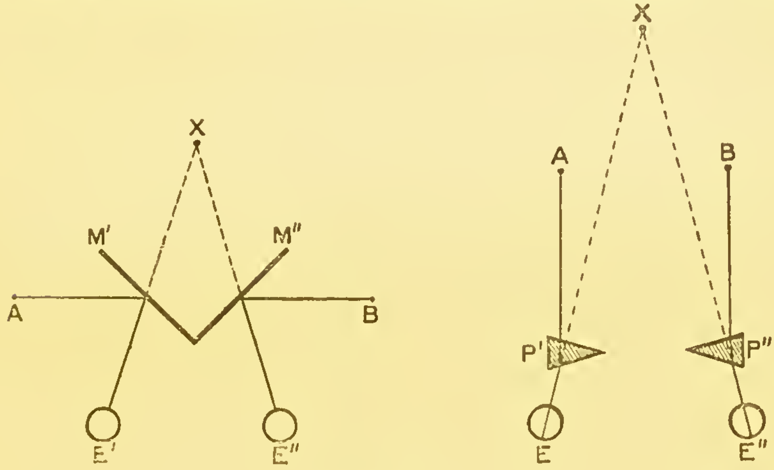

FIG. 54.

stereoscope (fig. 54). Owing to the action of the mirrors, M′ M″, or of the prisms, P′ P″, the objects A and B are combined by the two eyes, E′ E″, and referred to X.

DIPLOPIA.

Exp. 125. The image of a single shilling placed as before on a glass plate, may be doubled, the fixation point (of a pencil) being nearer to or further than the coin. The student should observe the different effect produced upon the doubled image in the two cases by closing one eye, and correlate these differences with the disparation (page 274).

THE CYCLOPEAN EYE.

Exp. 126. A piece of paper is held horizontally before the eyes, on which two parallel lines have been drawn, separated by a distance

equal to that between pairs of corresponding points. When the gaze, travelling over the two lines along the surface of the paper, is directed to a distant point, only a single line will be seen, situated midway between the two eyes.

Failure to Identify the Eye Stimulated.

Exp. 127. The experimenter takes a large sheet of black cardboard, pierced with a minute aperture, and he moves the card continuously but irregularly in front of the observer's face, so that light is admitted through the aperture, now to one, now to the other eye. The observer will note that, after these movements have been carried on for a brief time, he is unable to tell which eye is receiving light when the experimenter ceases to move the card.

Depth and Retinal Disparation.

Exp. 128. Using the apparatus provided, the student moves the two vertical threads A and C (fig. 55) to such an extent apart that when the eyes are directed to a more distant point, on the opposite wall, the threads (one in front of each eye) yield a single combined image. Then he arranges another pair of vertical threads B and D, beside and in the same plane with the former pair, so that they also give rise to a combined image. He observes now the effect of slightly increasing or decreasing the distance between B and D, so that the retinal points, excited by B and D, are no longer corresponding but disparate.

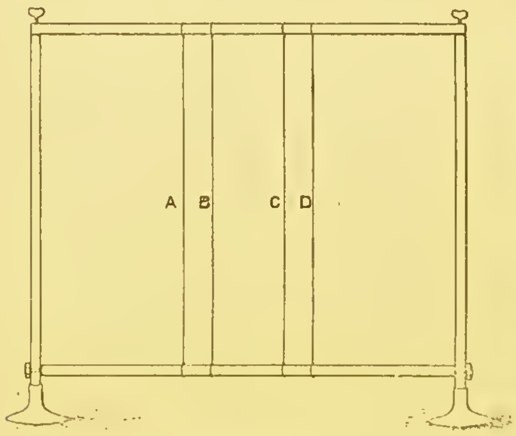

Fig. 55.

Hering's Fall Experiment.

Exp. 129. This experiment shows the difficulty of judging relative distance with monocular vision. Applying his eye to the end of a cardboard tube, the subject fixates a small bead, keeping the other eye closed. The experimenter drops successive beads in front of or

behind the point of fixation, and notes the correctness or incorrectness of the judgments given by the subject. A series of observations is then made when both eyes are open. The subject should at the same time keep an introspective record. It should be considered whether the apparatus in its rough form is altogether free from objection.

Binocular Rivalry, Combination and Lustre.

Exp. 130. The effects of binocular colour rivalry, combination and lustre should be studied in one or other form of stereoscope; coloured squares, black and white squares, and various designs and objects being used. The relation of rivalry to discrepancy in contour, intensity or brightness, should be observed.

Hering has devised an arrangement for showing binocular colour combination and rivalry, in which the two eyes look each through a differently coloured (*e.g.* a blue and a red) glass at a square of white light.

Figure 56 shows this arrangement. B and R are the blue and red glasses, fixed with their edges juxtaposed in the dark box, to one end of which the eyes, E^1 and E^2, are applied. At the other end are three squares of ground glass, *b*, *m*, and *r*, through which the observer gazes on to a uniform white surface, *e.g.* a clouded sky.

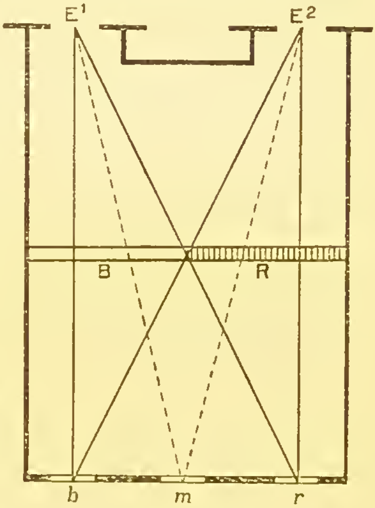

Fig. 56.

Under these conditions, the two lateral squares are coloured according to the glass placed before the eye, while the central one shows alternating colour combination and rivalry.

Binocular Contrast.

Exp. 131. By fixating a nearer point, the student produces double images of a white stripe on a black background. He places a red glass before the one eye and an equally bright grey glass before the other. He observes if the image seen through the grey glass is tinged with green (the complementary colour to red). He then removes the red glass and observes that the image, yielded by the eye which has been covered with the grey glass, becomes a well-marked red.

Exp. 132. The light of a window is allowed to fall laterally on one eye, while the other is consequently more shaded. The student now doubles the image of a white stripe on a black background by fixating a nearer point. He observes the difference in brightness and colour of the two images.

This experiment is called Fechner's side-window experiment, and is dependent on the exposure of one eye to a brighter light which enters the eye through the sclerotic and iris, acquiring a reddish tinge owing to its passage through a layer of blood vessels. Retinal adaptation and binocular contrast afford a partial explanation of the effects.

Exp. 133. The effects of uniocular contrast and binocular combination are observed in a simple apparatus devised by Hering, in which a black stripe on a white ground is doubled by fixation of a nearer point, and is viewed by one eye through a red, by the other through a blue glass.

Binocular Brightness.

Exp. 134. The observer places a moderately dark grey glass before one eye which is closed, while the other regards a white surface. He observes the brightness of the latter, and he compares it with its brightness when the shaded eye is opened and the surface is regarded binocularly.

Listing's Law.

Exp. 135. This law may be verified by projecting the after-image of a rectangular cross on to various points on a plane surface. Figure 57 represents a conveniently prepared surface, the centre of which is occupied by a coloured cross. The head of the subject is comfortably fixed so that it cannot move when the eyes are turned. The subject is seated so that his eyes, when regarding the cross, are in an approximately primary position. This position the subject finds by fixating the cross and by then turning the eyes to one or other of the points *a*, *b*, *c*, *d*. If the outline of the various after-images takes the direction of the horizontal and vertical ruled lines of the surface, the primary position of the eyes has been found. If the surface can be suitably rotated round its centre, the corresponding condition will be found to hold good for oblique as for horizontal and vertical positions of the arms of the cross.

Let the eyes be obliquely turned so as to project the after-image of the vertical and horizontal arms of the cross on to the points *e*, *f*, *g* or *h*. The unequal displacements, which the arms of the after-images undergo, are shown by the drawings of the cross at

these points in figure. But were the surface of projection a large hemisphere corresponding to the curved surface of the retina, instead of being a plane, these distortions would not occur, and thus Listing's law would be verified. The distortions with which we meet are due to our interpretation of the ruled lines as being truly horizontal and vertical in spite of the fact that the eyes are now regarding them in an oblique instead of in the primary position. Save in the primary position of the eyes, horizontal and vertical lines must really give rise to oblique retinal images. But since these lines are interpreted as being free from obliquity, a corresponding obliquity is transferred to the actually horizontal and vertical bars which form the after-image of the cross.

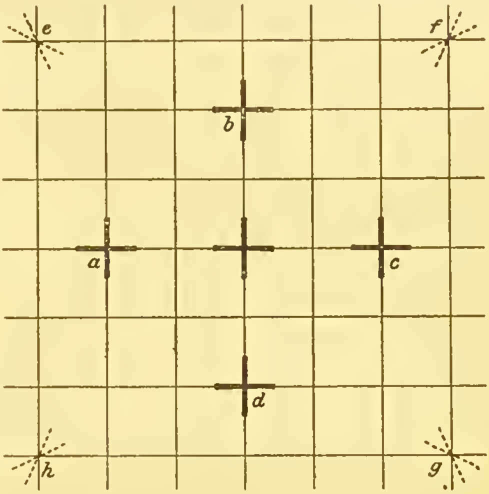

FIG. 57.

EXERCISES ON CHAPTER XXI

Binaural Experience

INFLUENCE OF BINAURAL DIFFERENCES OF INTENSITY AND TIMBRE.

Exp. 136. The subject is seated blindfold in a chair, his head supported by a rest. If a "sound perimeter" be available, the experimenter can systematically investigate the frequency and nature of the errors in localisation (i.) according to the direction of the sound, (ii.) according to the nature of the sound, and (iii.) according to the practice of the subject.

A sound perimeter consists of a graduated metal framework, supporting the source of sound and permitting the latter to be noiselessly moved in various directions relatively to the subject.

The "buzzer" of a telephone, carried on the perimeter, will serve as a complex sound stimulus; an electrically driven tuning-fork,

driven by a distant electrically driven fork and battery, will serve as a purer tone stimulus.

The experimenter divides the horizontal and sagittal planes of space in the following manner. The subject is supposed to be seated in an imaginary sphere the centre of which lies midway between his ears. The two points on the mid-horizontal plane of the sphere, which mark the poles in front of and behind him, are regarded as 0° and 180° respectively; the two points lying to the extreme right and left of him are regarded as 90° and 270° respectively. The sagittal plane is similarly divided, 90° being the position of a point above the vertex of the subject.

In the absence of a perimeter, the accuracy of auditory localisation may be roughly investigated by four experimenters standing respectively in front of, behind and to each side of the subject, upon a graduated chalk circle about two metres in diameter, drawn on the floor. Each experimenter holds between thumb and forefinger two coins, which, when clicked, serve as the source of sound. One of the experimenters directs the movements of the others, noiselessly indicating to one or other of his colleagues that he is to give the sound at any point within his own quadrant.

In the absence of an electrically vibrating tuning-fork, two ordinary forks of identical pitch may be employed, held by separate experimenters who stand one on each side of the subject. Both forks are struck simultaneously by preconcerted signal; but, by prearrangement, one of them is damped immediately after being struck. The subject states, as before, the direction from which he supposes the sound to come. The object of striking two forks is to limit the basis of the subject's answers to sensations of tone and to exclude those of noise.

The blindfold subject verbally describes the direction from which the sound appears to come to him, and one of the experimenters carefully records the actual and the apparent direction of the sound. The following results may be expected :—

(1) Fairly accurate localisation in the horizontal plane.

(2) Gross errors of localisation in the vertical sagittal plane, especially for pure tones, diminishing on practice.

(3) Tendency to confuse sounds in the horizontal plane which lie symmetrically with regard to the transverse (coronal) plane, *e.g.* to interpret a sound at 45° as coming from 135°.

The subject should endeavour to examine introspectively the basis of his several judgments, and from time to time he should, if possible, give the results of such introspections which are to be recorded by the experimenter beside the subject's estimations. If he finds it too

difficult to attend simultaneously to the act of localisation and to the mode of localisation, a series of experiments may be subsequently conducted, in which his attention is more completely concentrated on the introspective aspect of the records, even at the expense of loss of accuracy of localisation.

At the same time, the experimenter should be on the look-out for peculiarities in the behaviour of the subject which may throw light on the psychological basis of his power of localisation.

Exp. 137. Two vibrating forks are placed one on each side of the subject. If the forks are in unison, and affect the two ears equally, the sound is localised in the middle line.

INFLUENCE OF BINAURAL DIFFERENCES OF PHASE.

Exp. 138. If the forks give beats with one another, the sound will be alternately localised at different ears. Now, in the cycle between any two beats, the differences in phase between the two ears assume every possible value. Supposing that the right hand fork is the higher, the right hand effect will be found to follow binaural agreement in phase, the left hand effect to follow opposition in phase.

It will also be found that, as the forks approach the ears, the localisation becomes intra-cranial, *i.e.* the sound is heard within the head.

Exp. 139. The subject places the two ends of a long tube one in each ear, and closes his eyes, the tube resting on a table. The

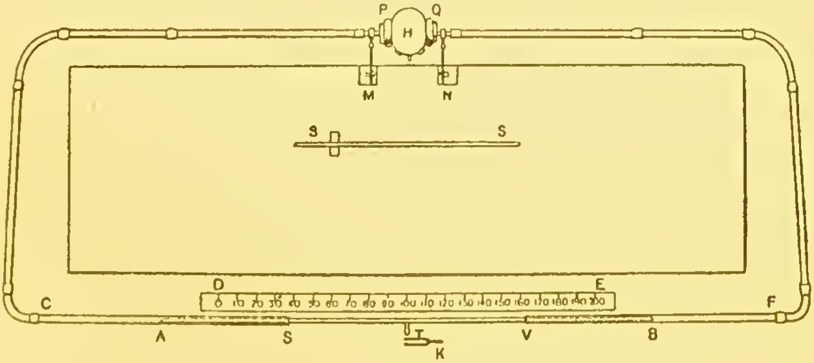

FIG. 58.

experimenter lightly sets a vibrating tuning-fork on the tube, along which he moves it now in one direction, now in another. The

subject localises the tone intra-cranially, the tone wandering within the head from one ear to another, according to the direction of binaural difference in intensity or wave length.

The arrangement of apparatus, shown in figure 58, enables the apparent influence of binaural phase difference upon localisation (page 287) to be more strikingly shown. Here the tuning-fork K is applied to the open end of the T-piece, T, the long limb of which is a brass tube AB, sliding within the slightly larger tubes AC, BF. The opening T can be brought to any position of the scale DE, between 40 and 160 cm. H is the head of the subject, whose view of the position of T is prevented by the screen SS. Against his head are pressed the two padded ear caps, P and Q, which, supported on retort stands M and N, receive the sound from the tubes AC, BF. If x be the distance of T from the centre of the scale, and if λ be the wave length of the tone, the tone is localised on the (experimenter's) right of the centre for values of x between 0 and $\frac{\lambda}{4}$, on the left of the centre for values of x between $\frac{\lambda}{4}$ and $\frac{\lambda}{2}$, and correspondingly for higher values of x.

Many subjects are able to give to such intra-cranial tones a definite localisation (*e.g.* in the pharynx or cerebellum) and can accurately describe the path of the tone as it passes from ear to ear.

EXERCISES ON CHAPTER XXII

The Visual Perception of Size and Direction

Projection of After-Images.

Exp. 140. The subject projects the after-image of a square object on to surfaces at different distances from the eye, and observes the varying size of the after-image. He also projects the after-image of a cross on to planes variously inclined with respect to the eye, and observes the varying distortion of the after-image.

Measurement of Optical Illusions.

Exp. 141. A subject and experimenter, after they have familiarised themselves with the commoner forms of geometric optical illusions, should proceed to the quantitative estimation of one of them after the following model.

The apparatus may consist of a board covered with black cloth, on the surface of which appear two white lines at right angles to one another. By a simple contrivance at the back of the board, the lengths of these lines may be easily varied. The experimenter sets the horizontal line at 100 mm. and the vertical line at a few mm. in length, and gives the board to the subject, who has to prolong the vertical line until it appears equal in length to the horizontal line. While he is lengthening the vertical, the subject must be careful that the board is in a constant horizontal (or vertical) position directly below (or in front of) him. By means of compasses, or by applying a scale to the board, the experimenter notes and records the actual length of this vertical line. He then reduces the vertical to a few mm. in length and asks the subject to repeat the estimation. Ten such values should be obtained, and their mean and mean variation determined.

Ten estimations should then be made by the subject, when the vertical is initially longer than the horizontal and has to be shortened by the subject until the two lines appear equal in length.

The mean error and variability for the twenty estimations can then be calculated, and a comparison can be made of the error and variability of estimation when the vertical is presented to the subject (i.) longer and (ii.) shorter than the horizontal line.

By turning the board successively through 90°, 180,° and 270°, three further series of observations should be made in order to compare the various errors of estimation, according as the vertical lies to the right of, to the left of, or above or below the horizontal line.

Experiments may also be conducted, in which the vertical line preserves a constant length of 100 mm., and the horizontal has to be made equal to it by the subject.

A very simple apparatus may be also contrived for measuring the Müller-Lyer illusion; the two parts of the illusion being combined as shown in the upper portion of figure 17 (page 300). The right-hand half of the figure, with both pairs of end lines, is drawn on a thin white xylonite surface. This part of the apparatus is fixed and forms a framework, to the left of which a thin board of the same material slides in and out, bearing the remainder of the figure. The board can be drawn out or pushed in beneath the framework, until the two sections of the horizontal line appear equal.

EXERCISES ON CHAPTER XXIII

Time

Reproduction of Intervals.

Exp. 142. The student should familiarise himself with the apparatus devised for recording equal intervals of time on the smoked surface of a revolving drum. An electrically vibrating tuning-fork may be connected in the same circuit with a time marker (fig. 38).

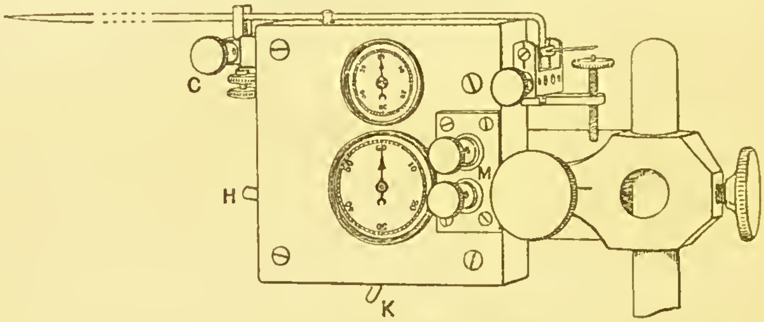

Fig. 59.—Clock Time Marker.

The upper of the two dials records minutes, the lower seconds. The clock is started and stopped by the lever H. Movement of the lever K restores the clock hands to starting-point (60). The clock is wound by turning a nut on the side opposite to that shown in the figure. On the same side is a small stud which changes the rate of movement of the recording lever. This can be made to rise and fall every second or every fifth of a second. Its excursions may be recorded directly on a travelling smoked surface, or they may be used to interrupt either of two electric circuits, the terminals for which are shown at M.

But it is more convenient to use a specially devised clock (fig. 59), bearing a lever which records fifths of seconds or whole seconds, as desired.

The recording apparatus should, even for class purposes, be set up in a different room from that in which the subject sits whose accuracy of time estimation is under investigation. The most reliable method of presenting to the subject any desired interval of time is attained by the use of a uniformly rotating metal arm which during rotation comes into contact with two (or more) sets of terminals; the result of such contacts being to close (or to open) electric circuits, and thereby to produce two or more (*e.g.* telephonic) sounds absolutely alike in

character and separated by an interval dependent on the rate of rotation of the metal arm, and the distance between any two sets of the metal terminals, which can be accurately varied at will.

In place of this apparatus (fig. 60) the interval may be presented to the subject by two auditory signals, given from the room in which the recording apparatus stands, and transmitted to the subject by means of a telephone "buzzer." Or still more simply, a second individual sitting not too near the subject, with a watch in hand,

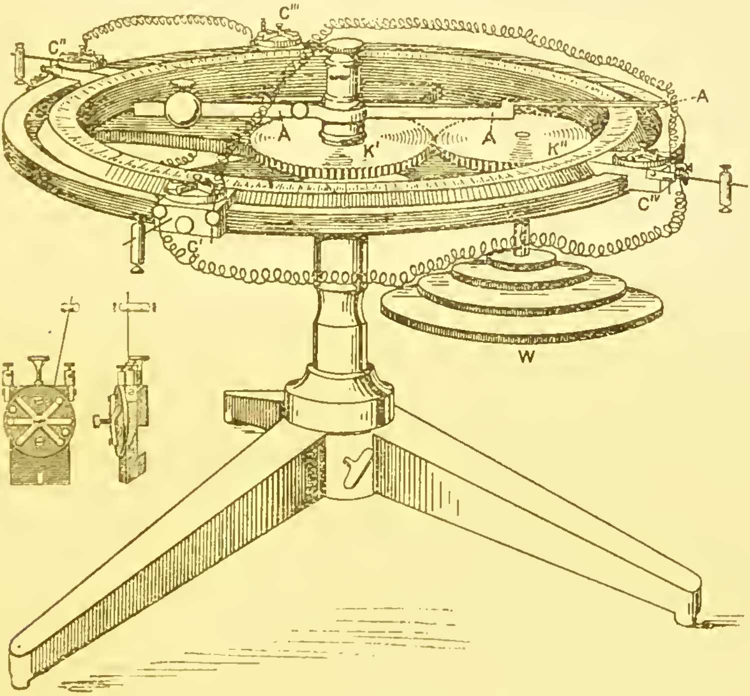

FIG. 60.—The Leipzic "Time Sense" Apparatus.

The arm A is driven by the cog wheels K′ K″, and these by the wheel W, which is connected with a reliable (clockwork or other form of) motor. As it revolves, the arm touches a number of contacts, C′, C″, C‴, C^{iv}. A contact, drawn from two aspects, is separately shown in a corner of the figure.

may give the two stimuli by tapping twice on a Morse key, and the time estimation is made by the subject tapping similarly on a second key.

If Morse keys are used, they should be so arranged that the taps made on each are communicated to a single time signal which is brought to write on the recording surface of the drum directly above

the movements of the lever of the time marker. By this arrangement, both the length of the interval presented by the experimenter and the estimated interval returned by the subject can be measured and compared. The experimenter must be careful to mark each of the experimenter's intervals on the drum, so that later he can always distinguish them from the subject's intervals. The two keys may be used in a variety of ways. The interval between two taps, *a* and *b*, having been given by the experimenter's key, the subject may be required to make a third tap *c* on his key, when the interval between *b* and *c* appears to him equal to that between *a* and *b*. Or the subject may be required to make two taps, *c* and *d*, on his own key, separated by an interval equal to that between *a* and *b*, given by the experimenter. In this case, the intervals of the experimenter and subject may be recorded on separate time markers. Or, again, the experimenter, after having given *a* and *b*, himself gives the tap *c* after a definite fixed interval has elapsed, the subject being enjoined to give the fourth tap *d* on his own key when the intervals between *c* and *d* and between *a* and *b* appear to him equal.

By one of these methods, a series of experiments should be made for intervals of different length ; five tests, for example, being made for intervals lying between 10 and 12 seconds, five for intervals between 5 and 6 seconds, five for intervals of about 4 seconds, five for 3, and so on for 2, $1\frac{1}{2}$, 1, $\frac{1}{2}$ and $\frac{1}{4}$ seconds. The sounds should be given with uniform loudness, and between each group of five tests the subject should carefully record the results of introspective analysis. When the interval is very small, the experimenter will himself be unable to present it exactly, but this is of little moment as the interval which he presents will be accurately measurable on the drum to which his taps are transmitted.

The percentage error, positive or negative, should be calculated for each estimation, and the nature and extent of the error for the different lengths of intervals, together with the position of the indifference point, should be investigated. The results may be further treated in their original groups of five, with the object of testing the variability of the error for different lengths of interval, but for reliable results a greater number of data must be obtained, and the order in which they are obtained must be taken into consideration.

Comparison between Filled and Empty Intervals.

Exp. 143. A series of experiments should be devised and carried out to show the effect on time estimation which occurs when the interval between the two taps, *a*, *b*, is filled with other taps, instead of

being silent. Two intervals are successively presented, the one filled, the other empty, and the subject has to determine whether the intervals are equal or unequal. The time order of presentation of the intervals should be varied, and either the limiting or the constant method should be used to determine the amount of the illusion.

Rhythm

Subjective Accentuation in Rhythm.

Exp. 144. The metronome is a convenient instrument for observing the subjective accentuation of the simplest rhythm. But care must be taken that no objective accentuation of its beats exists.

The experimenter should set the metronome at various rates of oscillation, so that the subject may appreciate the relation between rate of rhythm and ease of subjective accentuation. The subject should observe and record the varying affective values (pleasant, wearisome, etc.) of different rhythms and the associated experiences which they may revive. The experimenter may notice unconscious movements on the part of the subject.

Objective Accentuation.

Exp. 145. The effects of varying the objective accentuation are easily studied by enclosing the metronome in a box, the lid of which may be silently opened and closed at any moment so as to allow any desired sound to be intensified and so to be accented. Trochaic – ᴗ, iambic ᴗ –, dactylic – ᴗ ᴗ, anapæstic ᴗ ᴗ –, and cretic – ᴗ – measures should be studied. The effect of accenting the first of every four, five and six beats should be studied for different rates of rhythm.

Accuracy of Reproduction of Rhythm.

Exp. 146. The accuracy with which the reproduction of a given rate of rhythm can be maintained, may be investigated by means of the metronome; the subject reproducing the rhythm by tapping on a Morse key, the movements of which are transmitted to the recording surface of a drum in another room. The subject begins to tap synchrònously with the metronome sounds, and after, say, twenty sounds have been heard, the metronome is stopped while the subject continues his tapping. The time signal or clock (fig. 59) records fifths of seconds on the drum below the tracings made by the taps of the subject.

The relation of respiratory movements to rhythmical action and

to the estimation of time may be studied by attaching a pneumograph (fig. 63) to the subject and by connecting it with a tambour (fig. 64) brought to bear on the recording surface.

EXERCISES ON CHAPTER XXIV

Attention

Fluctuations of Attention.

Exp. 147. The subject is seated in a silent room or gallery,—or, better still, out of doors on a quiet night. The experimenter holds a watch opposite one ear of the subject, and, keeping it at this level, withdraws it in a straight line from the subject, until the latter can only just hear the ticks. The watch may be hidden in a cloth if it tick too loudly. Care must be taken that the alternations of sound and silence, now experienced by the subject, are not complicated by any objective variations in the loudness of the ticks. The alternations may be graphically recorded, as in the following experiment.

Exp. 148. When a white disc, bearing a thick broken black line on an imaginary radius (fig. 61), is rotated on the colour wheel, a series of grey bands is observed which become increasingly faint towards the periphery of the disc. The subject, comfortably seated, with his head supported by a head rest, fixates the faintest grey ring he can distinguish. He observes the fluctuations that it undergoes.

After a little practice, he will find no difficulty in recording these fluctuations, by varying the pressure of his finger on a rubber bulb which is connected with a recording tambour (fig. 64). The lever of this tambour and a time marker are brought to bear on the travelling smoked surface of a drum or kymograph. The recording instruments should be placed at some distance from the subject, to prevent distraction. The kymograph should rotate quite slowly, say twice in three minutes. The record should be interrupted after a single revolution of the kymograph; a longer sitting becomes unsatisfactory, owing to inattention.

The experiment may be modified in various ways. Instead of a rubber bulb, which permits of a continuous record, a reaction key may be used. Instead of the faintest ring, a ring somewhat less faint may be fixated. The background, instead of being white, may be black and the line white. The degree of attention given by the

subject to the ring may be experimentally varied. The relation of respiratory movements (exp. 151) to these fluctuations may be graphically studied.

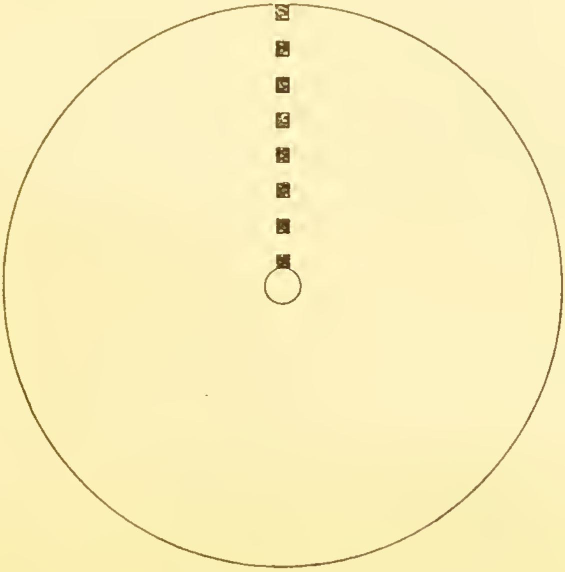

FIG. 61.

It is essential that the graphic records obtained by the experimenter be supplemented by careful introspection on the part of the subject.

THE SPAN OF APPREHENSION.

Exp. 149. The essentials of a good tachistoscope have been already mentioned in the text. Several forms of the instrument have been devised. (*a*) In the fall tachistoscope, a screen carrying a fixation mark is allowed to drop. During its fall, it momentarily exposes a card on which various objects, *e.g.*, letters or figures, are arranged.

(*b*) In the rotatory tachistoscope, the subject looks down a narrow vertical blackened tube on to the periphery of a large horizontally rotating white disc, which is driven by a very steady motor. The disc has a sector cut out from its margin. The open sector allows the subject to see a card of letters, etc., placed below the disc. The rate of rotation of the disc, the area of the sector, and hence the time of exposure, can be varied at will. Fixation is secured by a preliminary trial in which an easy letter is shown in place of the card of objects.

(*c*) In the pendulum tachistoscope (fig. 62), an oblong screen C, provided with a central aperture, is fixed to the free end of a pendulum. The pendulum is held up by an electro-magnet, and released at the desired moment. During its swing the screen momentarily exposes the objects which lie behind it. At the end of its swing it is caught by the catch D. An optical arrangement can be fitted to the pendulum tachistoscope, by means of which the images B of stencilled lines, letters, or figures, placed behind the screen, can (during the momentarily favourable position of the aperture) be thrown forward by aid of the condenser A and the lens E on to a plate of ground glass

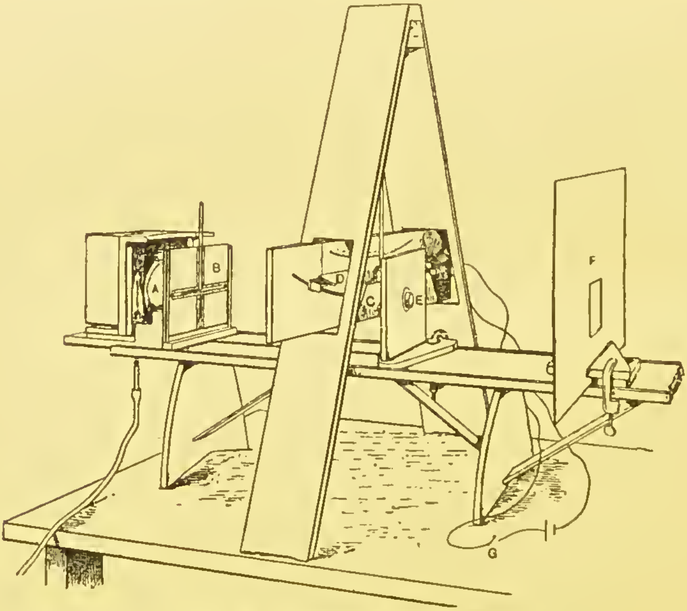

Fig. 62.—Hales's Tachistoscope.

at F, which carries a fixation mark fixated by the subject. The subject's head is supported by a head rest.

Whatever instrument be employed, the student should proceed in the first place to determine the maximum span of apprehension, keeping to a uniform time of exposure and varying only the number (not the nature) of the objects exposed. Dots, differing in number and in arrangement within a given area, form a suitable material.

A warning signal is given at a fixed time, say a second, before the object is exposed. After the object has been once exposed, the subject describes what he has seen. The experimenter may use the limiting method, proceeding from a single dot to two, three, four or more dots until the limit of the range of attention is passed. Or he may use the

constant method, varying the order of exhibition irregularly, and observing the proportion of right and wrong answers for different numbers of dots.

Exp. 150. The student should next proceed to investigate the influence of meaning and previous familiarity upon the range of attention, by exposing letters grouped in senseless and in sensible combinations.

Careful introspective records should always be made by the subject and subsequently correlated with the results obtained by the experimenter.

EXERCISES ON CHAPTER XXV

Feeling

N.B. The brief description of the few following instruments is only intended to give the student an idea of the general principles on which they are constructed. The details of the instruments are certain to differ in different laboratories. It must be left for the teacher to indicate, and for the student to learn by experience, the exact methods of manipulation. The tracings, made by the instruments on a recording surface, need to be accompanied by two other tracings. Of these the one records time intervals of a second, while the other indicates the moments of applying and discontinuing the stimulus which is to cause a change of feeling.

THE PNEUMOGRAPH.

Exp. 151. This instrument records the rate and extent of respiratory movements. In the simple form figured (fig. 63), it consists of a metal

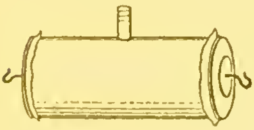

FIG. 63.

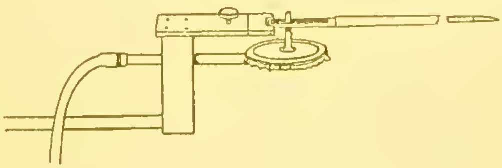

FIG. 64.

cylinder closed at the two ends by rubber sheeting. A hook is attached to the centre of each piece of rubber, the two hooks being connected by a piece of tape which passes tightly round the chest of the subject.

The fluctuations of air pressure within the pneumograph, thus produced by respiratory movements, are communicated to a recording tambour (fig. 64) by means of a side opening in the metal wall of the cylinder to which a piece of rubber tubing is attached.

In a complete investigation of respiratory movements, two pneumographs should be employed, since variations in the thoracic movements are by no means always accompanied by like variations in the abdominal movements of respiration.

The Sphygmograph.

Exp. 152. This sensitive instrument (of which there are very different forms), when applied to the pulse, *e.g.* at the wrist, responds to minute changes in arterial pressure. These changes, constituting the pulse, are communicated by levers to a recording surface. Variations in the form of the pulse curve or in the frequency of the pulse are indicated on the sphygmographic record.

The Plethysmograph.

Exp. 153. This consists of a closed chamber in which part of the body, usually the forearm, comfortably rests. The chamber is connected with a distant tambour, so that any variations of pressure due to increased or decreased volume of the arm are transmitted to a recording lever. In some patterns of the instrument, the chamber enclosing the arm contains air, but more usually the air is replaced by lukewarm water.

The Automatograph.

Exp. 154. In investigating the effect of pleasant and unpleasant stimuli upon the contraction of skeletal muscle, it is of course essential that the subject should so far as possible remain in ignorance of the effects which are expected to occur, and that the effects which have occurred should be concealed from him until all the desired experiments are completed.

The automatograph is a convenient instrument for recording involuntary movements of the arm (fig. 65). It is a freely swinging "planchette" A B, in which the arm comfortably rests. The slightest to and fro, or lateral, movement of the apparatus is communicated by a glass style C to an underlying piece of smoked paper. The subject's eyes are closed throughout the experiment.

The movements of the automatograph should first be studied when the subject preserves a dreamy attitude of complete indifference.

After this has been done, the experimenter observes the effect of introducing a pleasant or unpleasant stimulus. Odours (*e.g.* asafœtida, castor oil, musk, jockey club) are the easiest to use; they can be silently brought beneath the subject's nostrils. Their effect on involuntary movement is to be carefully noted by the experimenter

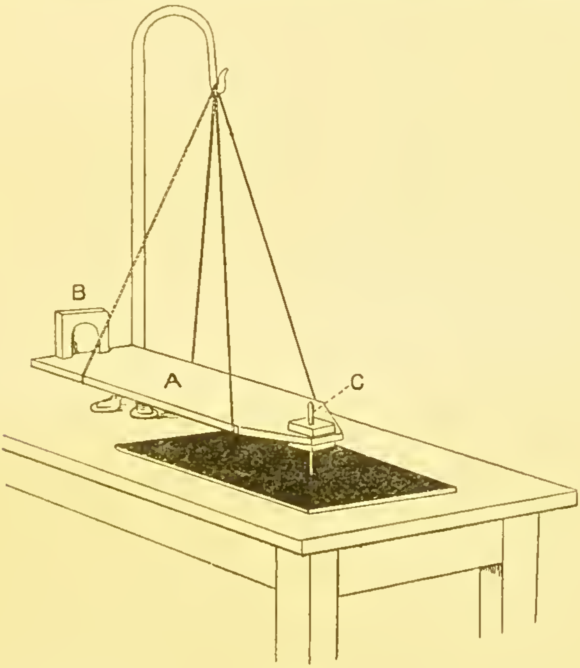

Fig. 65.

and correlated with the introspective record subsequently obtained from the subject.

It is important that a given odour should not be brought into the room until it is needed, and that the subject should be given ample rest between the applications of different stimuli.

The Recording Dynamometer.

Exp. 155. For rough work the instrument figured below (fig. 66) will suffice. Its purpose has been sufficiently indicated on page 334. A very slowly rotating drum should be used to record the movements of the lever L. The subject is enjoined to make a maximal contraction at F and to concentrate his attention on maintaining this degree of contraction for about a minute. The eyes are closed as before. A time signal records seconds upon the drum. A preliminary tracing is

taken with the subject in an indifferent state. The subject should carefully analyse the state of his conciousness throughout the experi-

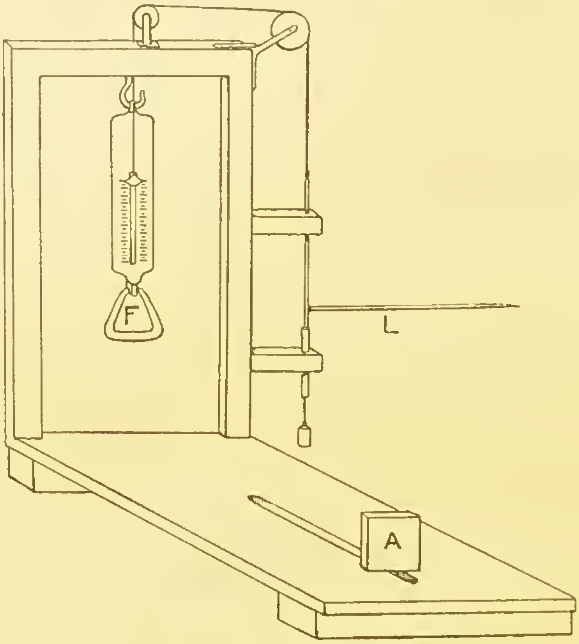

FIG. 66. (After Titchener.)

ment. After adequate pauses, tracings are taken in which the state of indifference is replaced by one of pleasure or displeasure, owing to the exhibition of an appropriate stimulus at recorded times.

INDEX

[*The numbers refer to the pages.*]

THE END

Printed by Morrison & Gibb Limited, *Edinburgh*

SELECTIONS FROM MR. EDWARD ARNOLD'S LIST.

AN INTRODUCTION TO CHILD STUDY.

BY W. B. DRUMMOND, M.B., C.M., F.R.C.P.E.,

Medical Officer and Lecturer on Hygiene to the Edinburgh Provincial Committee for the Training of Teachers.
Author of 'The Child: His Nature and Nurture.'

Crown 8vo., cloth, **6s.** net.

Recognition of the value of the science of child-study is extending rapidly among those who have to do with the training of children. It is not always realised, however, that, in order to be fully profitable, and for the avoidance of pitfalls, the subject must be approached with caution and with a certain amount of self-preparation on the part of the investigator.

Upon the importance of this caution and self-preparation Dr. Drummond lays considerable stress; then, after describing methods of study, he passes on to treat in detail of the facts of growth, the senses, and the nervous system, health, fatigue and over-pressure, instincts and habits, forms of expression in speech and drawing, and moral characteristics.

He has an interesting chapter on the question of religion as a suitable subject for the child's mind, and concludes with a reference to peculiar and exceptional children.

THE CHILD'S MIND: ITS GROWTH AND TRAINING.

BY W. E. URWICK, M.A.

Crown 8vo., **4s. 6d.** net.

The author believes that the theory of education, which has been in the main dependent upon the philosophical system of Herbart and Froebel, stands in need of revision in the light of the scientific developments which have taken place since the days of those eminent writers. The genetic method, which deals with the process of growth, is the one most successfully followed in the sciences—biology, physiology, and psychology—which have most to do with modern ideas on education.

Hence this book aims at setting forth some results already obtained from a study of mind-growth as an organic process, and establishing a clear and definite connection between the natural processes of learning and the methods by which the mind should be taught and trained.

LONDON: EDWARD ARNOLD.

MANUAL OF HUMAN PHYSIOLOGY.

BY LEONARD HILL, M.B., F.R.S.,
Lecturer on Physiology, London Hospital Medical School; Hunterian Professor, Royal College of Surgeons; Examiner in Physiology for the Conjoint Board of the Royal Colleges of Physicians and Surgeons.

SECOND EDITION.

xii + 484 pages, with 173 Illustrations. Crown 8vo., cloth, **6s.**

This important work covers the ground of University Local and Science and Art Elementary and Advanced Examinations, and will be found useful for students training to qualify as teachers, nurses undergoing hospital training, and the higher classes of schools and colleges.

THE LAWS OF HEALTH.

BY D. NABARRO, M.D., B.Sc., D.P.H.,
Assistant Professor of Pathology and Bacteriology, University College, London.

viii + 184 pages. With Illustrations. Crown 8vo., cloth, **1s. 6d.**

COMMON AILMENTS AND ACCIDENTS AND THEIR TREATMENT.

BY M. H. NAYLOR, M.B., B.S.

Foolscap 8vo., paper, **1s.** net; cloth, **2s.** net.

THE ECONOMY AND TRAINING OF MEMORY.

BY HENRY J. WATT, PH.D.,
Lecturer on Psychology in the University of Glasgow.

Small crown 8vo., cloth, **1s. 6d.** net.

This little volume, written primarily for the use of teachers studying Psychology, will, it is hoped, be appreciated by all who desire to preserve and strengthen the faculty of memory. After a general introduction, the Author first discusses the Experimental Investigation of Memory. He then proceeds to deal with some general questions—*e.g.* as to whether all memory is mechanical, and goes on to enumerate the factors which influence memory, and incidentally how it can be trained and assisted. The following chapters are on 'Mental Imagery' and 'Thoughts,' and the volume ends with a series of twenty-three rules for the Economy and Training of Memory.

LONDON: EDWARD ARNOLD.

NEW AND REVISED EDITION.

FOOD AND THE PRINCIPLES OF DIETETICS.

BY ROBERT HUTCHISON, M.D. EDIN., F.R.C.P.,

Physician to the London Hospital and Assistant Physician to the Hospital for Sick Children, Great Ormond Street.

With 3 Plates iu Colour and numerous Illustrations in the text.
Demy 8vo., **16s.** net.

'Dr. Hutchison's work is one which deserves the careful attention of all who are engaged in medical practice. It presents, in a most readable and interesting form, the main facts and chief views respecting the nature of various foods and the principles of dietetics. We can strongly recommend Dr. Hutchison's book as one of the best and most thorough works on food and dietetics in the English language; it contains many valuable original observations made by the author, and we do not know of any treatise which contains so much information concerning the recent advances in this subject conveyed in such a concise and practical manner.'—*Edinburgh Medical Journal.*

THE BODY AT WORK.

BY ALEX HILL, M.A., M.D.,

Recently Master of Downing College, Cambridge; Author of 'An Introduction to Science,' etc.

With Illustrations. Demy 8vo. **16s.** net.

In the preface to this book Dr. Hill has himself described the chief aim with which it was written. He says: 'I have endeavoured to describe the phenomena of life, and the principal conclusions which have been drawn as to their interdependence and as to their causes, in language which will be understood by persons unacquainted with the sciences upon which physiology is based.' The book is therefore intelligible to the general reader, but this does not involve any sacrifice of scientific interest, and the professional student will find it a valuable and suggestive supplement to the more restricted course of instruction of the ordinary text-book.

LONDON: EDWARD ARNOLD.